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IN RE APPLN. OF:	ULRICH ET AL.
SERIAL NO.	09/637,843
FILED:	AUGUST 10, 2000
FOR:	PRODUCTS COMPRISING CORN OIL AND CORN MEAL OBTAINED FROM HIGH OIL CORN
GROUP ART UNIT:	1761
EXAMINER:	HARRY HORTON

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Evidence Appendix

[Copies of the references cited by the Examiner in making her obviousness rejection herein appealed are attached.]

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Related Proceedings Appendix

[Applicants are aware of no appeals or interferences that are related to this appeal.]

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LIVE STOCK FARMING PROMOTES PERMANENT AND PROGRESSIVE AGRICULTURE

FEEDS AND FEEDING

A Handbook for the Student and Stockman

By FRANK B. MORRISON

Emeritus Professor of Animal Husbandry and Animal Nutrition, Cornell University

Assisted by ELSIE B. MORRISON AND SPENCER H. MORRISON

First to Ninth Editions by the late W. A. Henry, formerly Dean of the College of Agriculture and Director of the Agricultural Experiment Station, University of Wisconsin. Tenth to Fourteenth Editions by W. A. Henry, assisted by F. B. Morrison. Fifteenth to Twenty-second Editions revised and rewritten by F. B. Morrison.

TWENTY-SECOND EDITION, *Unabridged*

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Twentieth edition translated into Spanish under the direction of A. Castro and published by the Corporacion de Fomento de la Produccion of the Chilean Government, Santiago, Chile, 1943.

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The first edit
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meal. Usually the manufacturers include just enough corn gluten meal in their corn gluten feed to meet safely a guarantee of 25 per cent protein or some lower percentage. They then sell separately the corn gluten meal in excess of the amount needed to produce the standardized corn gluten feed.

Corn gluten feed of the usual grades supplies about 70 per cent as much digestible protein as linseed meal, and is nearly equal to linseed meal in content of total digestible nutrients. The protein in gluten feed is not of good quality, and therefore gluten feed should not be used as the chief protein supplement for swine or poultry. Gluten feed is not quite so palatable as corn, oats, or wheat bran. It should therefore usually be mixed with such well-liked feeds.

The amount of phosphorus in corn gluten feed will depend on whether or not the corn solubles have been included in it. The average phosphorus content is 0.80 per cent, but it will be considerably lower if the corn solubles are not present. Because of the lime used in neutralizing the corn solubles, gluten feed usually contains more calcium than corn or the other grains.

Gluten feed made from yellow corn, as is usually the case, has a considerably higher vitamin A value than does yellow corn. The color of the gluten feed will show the kind of corn used.

Sometimes molasses is added to corn gluten feed to form *sweetened corn gluten feed.*

711. Gluten feed for dairy cattle.—Gluten feed is used chiefly for feeding dairy cows and is one of the most common protein-rich feeds for this purpose. Though gluten feed is best used as one of the ingredients in dairy concentrate mixtures, it has been fed with satisfactory results to dairy cows as the only or the chief concentrate.

In 5 New York experiments a simple mixture consisting only of corn gluten feed, corn gluten meal, ground corn, and ground oats, with or without molasses, gave as good results, when fed to high-producing dairy cows receiving very little legume roughage, as did a concentrate mixture having much more variety.[76] In another New York trial, when gluten feed formed one-half the concentrate mixture for dairy cows, the results were just as satisfactory as when a smaller proportion was fed.[77] Contrary to statements sometimes made, there is no scientific evidence that a large proportion of gluten feed increases mastitis in dairy cows.

In an Indiana experiment gluten feed was as satisfactory as linseed meal when fed as the only protein supplement to a ration of ground corn, corn silage, and legume hay.[78] Because of the lower protein content of gluten feed, it was necessary to use a larger proportion to balance the ration than in the case of linseed meal.

712. Gluten feed for other stock.—Gluten feed is a fairly satisfactory protein supplement for beef cattle, sheep, or horses. However, it has been inferior to linseed meal or cottonseed meal in the few experiments conducted with fattening cattle or fattening lambs.[79]

Occasionally, gluten feed is lower in price than corn grain. It may then be used as a partial or even a complete substitute for corn for fattening lambs or cattle. Thus fed to fattening lambs, gluten feed was worth only 86 per cent as much as corn per ton in Iowa trials.[80]

Gluten feed is not commonly fed to swine, as it is worth more for feeding to cattle. Because of the poor quality of protein in gluten feed, it is not satisfactory as the chief protein supplement in swine rations, even for pigs on pasture.[81] Gluten feed is rather bulky for swine, and it is not very palatable to them, although they will readily eat a mixture containing 10 to 15 per cent gluten feed. In general, gluten feed is not an economical addition to rations for swine unless the price per ton is less than that of corn or other grain.[82]

Gluten feed is not usually fed to poultry, but it can satisfactorily form about 10 per cent of the ration, replacing part of the other protein supplements.[83]

713. Corn gluten meal.—Corn gluten meal, commonly called "gluten

meal," consists chie
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Gluten feed for other stock.— d is a fairly satisfactory pro- ement for beef cattle, sheep, However, it has been inferior meal or cottonseed meal in periments conducted with fat- le or fattening lambs.[79] ionally, gluten feed is lower an corn grain. It may then be partial or even a complete for corn for fattening lambs Thus fed to fattening lambs, l was worth only 86 per cent corn per ton in Iowa trials.[80] feed is not commonly fed to t is worth more for feeding to ause of the poor quality of gluten feed, it is not satisfac- chief protein supplement in ns, even for pigs on pasture.[81] d is rather bulky for swine, ot very palatable to them, al- y will readily eat a mixture 10 to 15 per cent gluten feed. , gluten feed is not an eco- ddition to rations for swine price per ton is less than that other grain.[82]

feed is not usually fed to ut it can satisfactorily form er cent of the ration, replac- of the other protein supple-

Corn gluten meal.—Corn glu- commonly called "gluten

meal," consists chiefly of the corn gluten separated in the wet-milling process of starch manufacture, with practically none of the hull fragments. It may or may not include corn solubles and may occasionally contain some corn oil meal.

Gluten meal usually has more than 40 per cent protein, averaging 43.2 per cent. It has only 2.3 per cent fat, on the average, and is low in fiber. Gluten meal supplies nearly as much digestible protein as soybean oil meal, but the protein is not of high quality. Therefore gluten meal should not be used as the chief protein supplement for swine or poultry, but should be used with feeds which make good the deficiencies of corn protein.

Gluten meal is a heavy, concentrated feed and is higher than soybean oil meal in percentage of total digestible nutrients, averaging 79.7 per cent. When made chiefly from yellow corn, as is generally the case, gluten meal is even higher than gluten feed in vitamin A value, but it is much lower in calcium and phosphorus. Gluten meal is also very low in riboflavin.

714. Gluten meal for dairy cattle.—Gluten meal is mostly fed to dairy cattle and is a very satisfactory protein supplement for them, when fed in proper combination. Since it is much heavier than gluten feed, it is usually combined with bulkier feeds.

715. Gluten meal for beef cattle, sheep, horses, and swine.—Gluten meal is fed to beef cattle much less frequently than to dairy cows. For fattening cattle it gives fairly satisfactory results when fed as the only protein supplement, if the ration contains a reasonable amount of legume hay. Kansas experiments show that for fattening calves, the best results are secured from gluten meal when it is combined with linseed meal or certain other supplements.[84] However, a mixture of one-half gluten meal and one-half cottonseed meal was not much better than gluten meal fed as the only supplement. Probably a combination of gluten meal and soybean oil meal would give good results, because soybean oil meal has protein of excellent quality.

In 4 New York experiments corn gluten meal produced slightly less rapid gains than linseed meal, soybean oil meal, or ground soybeans, when each of these feeds was used as the only supplement for fattening yearling cattle full-fed corn grain, corn silage, and mixed hay.[85] Also, the selling price of the cattle fed gluten meal was a little lower, because they were not quite so well finished. In these trials the actual value of corn gluten meal was decidedly below that of the other supplements.

On the other hand, for wintering beef calves or yearlings in Kansas experiments, gluten meal was fully equal to cottonseed meal, linseed meal, or soybean oil meal as the supplement to sorghum silage.[86] The difference between the value of gluten meal in these trials and in the New York trials with cattle full-fed corn grain is probably due to the following: Fattening cattle full-fed grain eat relatively little roughage, and the quality of protein in corn grain is poor. Beef cattle being wintered consume mostly roughage, and the quality of the protein in satisfactory roughage, even non-legume, is better than in corn grain. (125)

Apparently because fattening lambs eat a much larger proportion of roughage than do full-fed fattening cattle, gluten meal gives decidedly better results as the only protein supplement for fattening lambs than for fattening cattle.

In 3 New York trials fattening lambs fed gluten meal as the only protein supplement to a low-protein ration made as rapid and economical gains as lambs fed soybean oil meal as the supplement.[87] These supplements were added to a ration of corn grain and corn silage, with little or no legume hay. Lambs fed linseed meal made a trifle more rapid gains than those fed gluten meal and were somewhat more easily kept on full feed. In New York metabolism experiments with growing lambs, the protein of gluten meal had as high a value as that of soybean oil meal or even that of milk. (127) For non-ruminants, the gluten meal protein would be of decidedly lower value.

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they furnish protein at lower cost than do such feeds as soybean oil meal or cottonseed meal.[12] Dairy cows will usually eat concentrate mixtures containing 8 to 17 per cent tankage satisfactorily. Occasionally some cows do not like such a mixture at first, though later they will eat it readily.

The milk production is not increased by substituting tankage or meat scrap for the protein supplements ordinarily fed dairy cattle, and it may even be reduced a trifle. These animal by-products have not affected the flavor or odor of the milk, even when fed 1 to 2 hours before milking.

Meat scrap or tankage can be used as a protein supplement in "calf starters," or calf meals, but had best replace only part of the dried skimmilk, other dairy by-products, or soybean oil meal.

907. Tankage or meat scrap for beef cattle.—Tankage or meat scrap is of much less value for beef cattle than for swine or poultry. In 10 experiments fattening cattle fed either tankage or meat scrap as the only protein supplement gained 0.1 lb. less per head daily than similar cattle fed linseed meal, cottonseed meal, or soybean oil meal as the supplement.[13] Where the selling price of the cattle was reported in these trials, it was slightly less for the cattle fed tankage or meat scrap. While the value of these animal by-products varied widely in these experiments, on the average they were worth less per ton than the plant-protein supplements.

Tankage was also inferior to cottonseed meal or corn gluten meal in Kansas tests in which 1 lb. per head daily of these various supplements was fed to calves and yearlings being wintered on Atlas sorghum silage.[14]

It is best to accustom cattle to tankage or meat scrap gradually by mixing a small proportion at the start with better-liked feeds, such as linseed meal, cottonseed meal, or ground grain. Tankage or meat scrap has given better results with beef cattle when used in mixed protein supplements, combined with such feeds as linseed meal, cottonseed meal, and soybean oil meal.

908. Tankage or meat scrap for sheep.—Tankage or meat scrap can be substituted for such protein supplements as soybean oil meal in feeding sheep. Sheep may not like these animal by-products at first, but after a few days will usually eat the small amount needed to balance the ration, especially if mixed with well-liked feeds. Sometimes fattening lambs tire of meat scrap or tankage toward the end of the feeding period.

The results of experiments in which either digester tankage or meat scrap has been used as the only protein supplement for fattening lambs have differed somewhat.[15] In some of the trials the results have been fully as good or even slightly better than with cottonseed meal or linseed meal, but in other tests the gains have been more rapid on the latter supplements.

909. Tankage or meat scrap for horses.—One to 2 lbs. a day of either of these feeds, or 1 lb. of blood meal, is sometimes useful for run-down, thin horses. As these feeds are not liked by horses, they must be mixed with palatable feeds.

910. Blood meal; blood flour.—*Blood meal*, or dried blood, is made from the blood collected at packing plants. It is first heated until it is thoroughly coagulated; the excess water is then drained off; more moisture is removed in a press; and finally, the solid residue is dried and ground.

Blood meal is the highest in protein of all the packing-plant by-products, containing over 80 per cent. However, the protein is less digestible and of much poorer quality than that in high-grade tankage or meat scrap. Blood meal is low in calcium and phosphorus, thus differing again from tankage or meat scrap. It is used chiefly in "calf starters," or calf meals, for raising dairy calves on a minimum of milk. Blood meal is not usually liked by calves at first, and if it is used as the chief protein supplement in a calf meal, it may be difficult to get them started on it.

Sometimes blood meal is used in poultry feeds, but it is unpalatable to

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poultry and is inferior to meat scrap in value.[46] Tankage is usually better and cheaper for young pigs.[47] In a Massachusetts test 10 per cent of blood meal was a fairly good substitute for other protein feeds in a concentrate mixture for dairy cows.[48]

Blood flour, or soluble blood meal, is produced by special processes, and is more soluble than ordinary blood meal. It is considered preferable in calf meals, but in an Ohio trial ordinary blood meal equaled soluble blood flour.[49]

911. Hoof and horn meal.—Experiments have shown that when animal hoofs and horns are ground to an extremely fine powder in a ball mill, the product can be digested by animals and can be used to replace part of the usual protein supplements for poultry. The product seems to be decidedly variable, however, and sometimes does not give satisfactory results.[50]

912. Feather meal.—Feather meal, or hydrolized feathers, is a new product made by treating under high steam pressure the feathers from slaughtered poultry. It has over 80 per cent protein, and according to the definition proposed by the Association of American Feed Control Officials, should have 70 per cent digestible protein.[22] The results of the few trials reported with feather meal have differed, apparently due to variations in quality.[51]

Feather meal properly made can apparently replace part of the ordinary protein supplements in rations. Satisfactory results have been reported with 2 to 5 per cent in a broiler mash. Feather meal seems to supply vitamin B_{12} and one of the unidentified factors needed by chicks. (222)

913. Liver meal.—Various types of liver meal, made chiefly from animal or fish livers, are used primarily as vitamin supplements, but also supply high-quality protein. *Animal liver meal* should be made entirely from liver. *Animal liver and glandular meal* is made from liver and other glandular tissue and at least 50 per cent of the dry matter should be from liver.[22] Similar products are made from fish by-products.

Liver meals are used chiefly as vitamin supplements in poultry mashes or in special feeds for pet stock and fur animals, because of the content of riboflavin and other B-complex vitamins. Adding 2 per cent of liver meal to a ration for very young pigs in dry lot may increase the thriftiness and gains, but may be uneconomical, because of the high price.[52]

914. Low-grade animal fat.—Due in large part to the wide use of detergents in place of soaps in this country, there has recently been a surplus of low-grade animal fats, produced in the meat and rendering industries. (134) As a result, the prices of these tallows and greases have declined to levels that make their use in formula feeds, or mixed commercial feeds, practical. The use of these fats is discussed in Chapter V and in the chapters dealing with the different classes of stock. To prevent the development of rancidity in the fat and resulting destruction of vitamins in the feed, an effective antioxidant should be added to the fat.

915. Paunch fluid, dried.—In Wisconsin tests a product rich in B-complex vitamins was prepared experimentally by pressing out and drying the fluid that could be pressed from the paunch contents of cattle or sheep at a slaughter house.[53] It was about as rich as dried skimmilk in riboflavin.

916. Poultry by-product meal.—This by-product of poultry processing plants consists of the ground, dry-rendered, clean, wholesome parts of the carcasses of slaughtered poultry, such as head, feet, undeveloped eggs, gizzard and intestines, exclusive of feathers and gizzard and intestinal contents, except in such trace amounts as might occur unavoidably in good factory practice.[22] Limited data indicate that it may be a satisfactory substitute for meat scrap.[54]

917. Fish meal.—Years ago most of the fishery wastes were either used to make fish meal for fertilizer or were not utilized at all, but dumped in the sea. Because of the numerous experiments which proved the high value of fish meal for swine and poultry, the production of fish meal has increased until it has become an important protein supplement.

Several types of fish meal are made, differing both in the raw material used and in the method of drying. Menhaden fish meal is the most common kind in the eastern states. This is made in processing menhaden herring (a very fat fish not suited for food) for fish oil and fish meal. White fish meal is made chiefly

from the cuttings or waste of t
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Fish meal of good quality
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from the cuttings or waste of the cod and haddock industry, not including the entrails, which, except the livers, are dumped at sea. Other fish meals are made of waste from sardines, herring, salmon, tuna, etc.

At first, fish meal was nearly all dried in so-called "flame driers," in which the material was exposed to high temperatures. This method has been largely replaced by drying in steam-jacketed drums, often under partial vacuum, to lower the temperature. Vacuum-dried fish meal is superior to flame-dried fish meal made from the same material, as it has a higher content of vitamins and the protein is more digestible.

In the case of fish cuttings that are high in fat or oil, most of the oil is expressed from the product. A high fat content in fish meal is undesirable, as such fish meal may produce a fishy taste in eggs, meat, or milk. Also, fish meal high in fat is more apt to become rancid on storage.

918. **Nutritive value of fish meals.**—Fish meals differ somewhat in nutritive value, depending on the type of raw material used, the method of drying, and the care taken in the process. But few direct comparisons have been made of the various kinds of fish meal, and therefore only general statements can be given concerning their relative feeding value.

Fish meal of good quality has an especially high value for swine and poultry, because of the excellent quality of protein it supplies. However, the protein quality in different samples of fish meal varies decidedly. In more than a hundred samples of various commercially produced fish meals recently tried in California experiments, only about half were rated as good in protein quality.[65] In these tests sardine fish meals, which comprised the greatest number of samples, were generally of high quality.

Apparently, some fish meal producers should use much more care in making their product. If decomposition of the fish waste occurs before it is processed, the fish meal may be injurious and entirely unsuitable for feeding. Obviously, much more care must be taken to prevent decomposition in the production of fish meal for stock feeding than in making fish meal for fertilizer. Certain fish waste is too high in salt to be used to make fish meal for feeding, unless the salt is removed from the product.

Fish meal is very rich in protein, containing 60.9 per cent, on the average. Also, the protein of good-quality fish meal is of high nutritive value, tending to be more efficient than the protein of tankage or meat scrap as a supplement to the grains. If fish meal contains too large a proportion of fish heads, the value of the protein is decreased, because much of the protein in the heads is less digestible and of lower nutritive value than the protein in the flesh.

Herring fish meal is the highest in protein content, averaging 72.6 per cent. Sardine, menhaden, and white fish meal all average above 60 per cent in protein, while fish meal from redfish, salmon, and tuna usually has somewhat less protein.

Fish meal usually has 6 to 10 per cent of fat, but some fish meal is now made which has only 3 to 4 per cent fat.

Because of the bones it contains, fish meal is high in calcium and phosphorus. It has an average of 5.36 per cent calcium and 3.42 per cent phosphorus, with a total mineral-matter content of 18.3 per cent. It should also be noted that fish meal usually contains an appreciable amount of iodine. However, in regions where there is an iodine deficiency for livestock, iodine can readily be supplied at less expense in the form of iodized salt. (170)

Fish meal is one of the richest sources of vitamin B_{12} among common feeds and also of one of the unidentified vitamins required by poultry. (222) It is also fair in riboflavin content and has considerable niacin. Fish meal processed under partial vacuum may contain considerable vitamin A and vitamin D, but other fish meals may have little of these vitamins.

Some have hesitated to use fish meal for stock feeding, fearing that it might cause a fishy flavor in eggs, meat, or milk. In the numerous feeding experiments

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one-half the roughage (on the dry basis) is alfalfa, soybean, or cowpea hay.

1.

Ground corn	1,160 lbs.
Ground oats	500 lbs.
Wheat bran	220 lbs.
Soybean oil meal (or cotton-seed meal)	100 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 9.8%
Total dig. nutrients, 75.3%

2.

Ground corn	1,130 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Linseed meal	150 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 9.8%
Total dig. nutrients, 75.1%

3.

Ground barley (or wheat)	1,030 lbs.
Ground oats	700 lbs.
Wheat bran	250 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 10.1%
Total dig. nutrients, 72.91%

4.

Ground corn	1,000 lbs.
Ground oats	640 lbs.
Wheat bran	200 lbs.
Corn gluten feed	70 lbs.
Soybean oil meal	70 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 9.8%
Total dig. nutrients, 74.5%

5.

Ground grain sorghum	1,400 lbs.
Ground oats	330 lbs.
Wheat bran	200 lbs.
Cottonseed meal (or soybean oil meal)	50 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 9.6%
Total dig. nutrients, 76.0%

6.

Corn-and-cob meal	1,310 lbs.
Wheat bran	500 lbs.
Cottonseed meal (or soybean oil meal)	85 lbs.
Linseed meal	85 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 9.6%
Total dig. nutrients, 70.9%

B. Mixtures for fitting dry cows and for freshening cows

Mixture No. 1, which contains somewhat more than 12 per cent total protein, is suitable for use when at least one-third of the roughage, on the dry basis, is legume forage. When little or no legume roughage is available, such a mixture as No. 2, which contains 16 per cent protein, is preferable.

1.

Ground corn	760 lbs.
Ground oats	600 lbs.
Wheat bran	500 lbs.
Linseed meal	100 lbs.
Bone meal (or other safe supplement)	20 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 10.2%
Total dig. nutrients, 72.0%

2.

Ground corn	590 lbs.
Ground oats	500 lbs.
Wheat bran	500 lbs.
Linseed meal	360 lbs.
Bone meal (or other safe supplement)	20 lbs.
Ground limestone	10 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 13.1%
Total dig. nutrients, 71.4%

C. Mixtures containing approximately 14 per cent protein

For cows in milk which are fed red clover hay (at least 1 lb. daily per 100 lbs. live weight) and corn or sorghum silage or corn or sorghum fodder, when protein supplements are expensive.

For cows in milk which are on very good pasture.

For dry cows when only one-fourth of the roughage (on the dry basis) is legume.

For heifers over 6 months old, when one-half the roughage (on the dry basis) is clover hay.

1.

Ground corn	1,055 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Soybean oil meal (or cotton-seed meal)	225 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 11.9%
Total dig. nutrients, 75.3%

A

2.

Ground corn	98
Ground oats	50
Wheat bran	20
Linseed meal	30
Salt	2
Total	2,00

Dig. protein, 11.5%
Total dig. nutrients, 74.8%

3.

Ground barley	1,09
Ground oats	60
Wheat bran	20
Soybean oil meal (or cotton-seed meal)	9
Salt	2
Total	2,00

Dig. protein, 11.5%
Total dig. nutrients, 73.6%

4.

Ground corn	95
Ground oats	50
Wheat bran	22
Corn gluten feed	15
Soybean oil meal	15
Salt	2
Total	2,0

Dig. protein, 11.8%
Total dig. nutrients, 74.7%

D. Mixtures containin

For cows in milk which are fed go clover or alsike clover hay (at least daily per 100 lbs. live weight) with silage, sorghum silage, corn fodder, so fodder, or roots.

For cows in milk which are fed mixed clover-and-grass hay (contain least 30 per cent clover) and corn ghum silage or corn or sorghum fodder, protein supplements are unusually exp

For cows in milk which are on goo ture.

For dry cows which are fed little legume roughage.

1.

Ground corn	
Ground oats	
Wheat bran	
Soybean oil meal (or cotton-seed meal)	
Salt	
Total	2,

Dig. protein, 13.9%
Total dig. nutrients, 75.1%

2.

Ground barley	1,
Ground oats	
Wheat bran	
Soybean oil meal (or cotton-seed meal)	
Salt	
Total	2

Dig. protein, 13.6%
Total dig. nutrients, 73.8%

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....	1,000 lbs.
....	640 lbs.
....	200 lbs.
..d	70 lbs.
..al	70 lbs.
....	20 lbs.
....	2,000 lbs.

1%
..nts, 74.5%

..orghum	1,400 lbs.
....	330 lbs.
....	200 lbs.
..l (or soybean	
....	50 lbs.
....	20 lbs.
....	2,000 lbs.

1%
..nts, 76.0%

..neal	1,310 lbs.
....	500 lbs.
..l (or soybean	
....	85 lbs.
....	85 lbs.
....	20 lbs.
....	2,000 lbs.

%
..nts, 70.9%

..ing cows

....	590 lbs.
....	500 lbs.
....	500 lbs.
....	360 lbs.
..r other safe	
....	20 lbs.
..e	10 lbs.
....	20 lbs.
....	2,000 lbs.

1%
..nts, 71.4%

..t protein

....	1,055 lbs.
....	500 lbs.
....	200 lbs.
..l (or cotton-	
....	225 lbs.
....	20 lbs.
....	2,000 lbs.

..9%
..ts, 75.3%

2. Ground corn	980 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Linseed meal	300 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 11.5%
Total dig. nutrients, 74.8%

3. Ground barley	1,090 lbs.
Ground oats	600 lbs.
Wheat bran	200 lbs.
Soybean oil meal (or cottonseed meal)	90 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 11.5%
Total dig. nutrients, 73.8%

4. Ground corn	955 lbs.
Ground oats	500 lbs.
Wheat bran	225 lbs.
Corn gluten feed	150 lbs.
Soybean oil meal	150 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 11.8%
Total dig. nutrients, 74.7%

5. Ground grain sorghum	1,275 lbs.
Ground oats	330 lbs.
Wheat bran	200 lbs.
Cottonseed meal (or soybean oil meal)	175 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 11.1%
Total dig. nutrients, 75.5%

6. Corn-and-cob meal	1,220 lbs.
Wheat bran	450 lbs.
Cottonseed meal (or soybean oil meal)	155 lbs.
Linseed meal	155 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 11.2%
Total dig. nutrients, 71.1%

D. Mixtures containing approximately 16 per cent protein

For cows in milk which are fed good red clover or alsike clover hay (at least 1 lb. daily per 100 lbs. live weight) with corn silage, sorghum silage, corn fodder, sorghum fodder, or roots.

For cows in milk which are fed good mixed clover-and-grass hay (containing at least 30 per cent clover) and corn or sorghum silage or corn or sorghum fodder, when protein supplements are unusually expensive.

For cows in milk which are on good pasture.

For dry cows which are fed little or no legume roughage.

1. Ground corn	945 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Soybean oil meal (or cottonseed meal)	335 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 13.9%
Total dig. nutrients, 75.1%

2. Ground barley	1,000 lbs.
Ground oats	560 lbs.
Wheat bran	200 lbs.
Soybean oil meal (or cottonseed meal)	220 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 13.8%
Total dig. nutrients, 73.8%

3. Ground corn	830 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Corn gluten feed	225 lbs.
Soybean oil meal (or cottonseed meal)	225 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 13.8%
Total dig. nutrients, 74.6%

4. Ground corn	820 lbs.
Ground oats	500 lbs.
Wheat bran	220 lbs.
Linseed meal	440 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 13.9%
Total dig. nutrients, 74.3%

5. Ground grain sorghum	1,180 lbs.
Ground oats	300 lbs.
Wheat bran	200 lbs.
Cottonseed meal (or soybean oil meal)	300 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 12.7%
Total dig. nutrients, 75.1%

6. Corn-and-cob meal	1,090 lbs.
Wheat bran	450 lbs.
Cottonseed meal (or soybean oil meal)	220 lbs.
Linseed meal	220 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 13.0%
Total dig. nutrients, 71.1%

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E. Mixtures containing approximately 18 per cent protein

For cows in milk which are fed mixed clover-and-timothy hay or other mixed clover-and-grass hay containing at least 30 per cent clover (at least 1 lb. of hay daily per 100 lbs. live weight), this hay being fed with corn or sorghum silage, corn or sorghum fodder, or roots.

For cows in milk which are on fair pasture.

For heifers over 6 months old, when only about one-fourth the roughage (on the dry basis) is legume.

1. Ground corn	685 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Soybean oil meal	270 lbs.
Distillers dried corn grains	325 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 14.7%
Total dig. nutrients, 75.8%

2. Ground barley	940 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Soybean oil meal (or cottonseed meal)	340 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 15.5%
Total dig. nutrients, 74.0%

3. Ground corn	680 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Corn gluten feed	300 lbs.
Soybean oil meal (or cottonseed meal)	300 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 15.5%
Total dig. nutrients, 74.3%

4. Ground corn	540 lbs.
Ground oats	500 lbs.
Wheat bran	200 lbs.
Linseed meal	370 lbs.
Corn gluten feed	370 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 15.1%
Total dig. nutrients, 73.5%

5. Ground grain sorghum	1,045 lbs.
Ground oats	300 lbs.
Wheat bran	200 lbs.
Cottonseed meal (or soybean oil meal)	435 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 14.4%
Total dig. nutrients, 74.5%

6. Corn-and-cob meal	970 lbs.
Wheat bran	450 lbs.
Cottonseed meal (or soybean oil meal)	280 lbs.
Linseed meal	280 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 14.5%
Total dig. nutrients, 71.1%

F. Mixtures containing approximately 20 per cent protein (Add 20 lbs. ground limestone per ton if roughage is grown on soil very deficient in calcium.)

For cows in milk which are fed mixed legume-and-grass hay containing less than 30 per cent legumes, this hay being fed with corn or sorghum silage, corn or sorghum fodder, or roots.

For cows in milk which are fed non-legume roughage of good quality and which are producing sufficient milk so that they require at least 8 to 10 lbs. of concentrate or grain mixture.

For cows in milk which are on poor pasture.

For heifers over 6 months old which are fed no legume roughage.

1. Ground corn	630 lbs.
Ground oats	400 lbs.
Wheat bran	200 lbs.
Soybean oil meal	370 lbs.
Distillers dried corn grains	380 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 16.7%
Total dig. nutrients, 76.4%

2. Ground corn	510 lbs.
Ground oats	300 lbs.
Wheat bran	200 lbs.
Linseed meal	470 lbs.
Corn gluten feed	500 lbs.
Salt	20 lbs.
Total	2,000 lbs.

Dig. protein, 16.9%
Total dig. nutrients, 73.9%

3. Ground barley
Ground oats
Wheat bran
Soybean oil meal (or cottonseed meal)
Salt
Total
Dig. protein, 17.6%
Total dig. nutrients, 74.4%

4. Ground corn
Ground oats
Wheat bran
Corn gluten feed
Soybean oil meal
Cane molasses
Salt
Total
Dig. protein, 17.4%
Total dig. nutrients, 72.1%

C. Mixtures containing approxim
per ton if roughage

For cows in milk which ar
quality non-legume roughage an
not producing sufficient milk tc
much as 8 lbs. of concentrate o
ture.

For cows in milk which o
non-legume roughage of fair to

1. Ground corn
Ground oats
Wheat bran
Soybean oil meal (or cotto
seed meal)
Distillers dried corn grains
Salt
Total
Dig. protein, 20.2%
Total dig. nutrients, 77.1%

2. Ground barley
Ground oats
Wheat bran
Soybean oil meal (or cott
seed meal)
Linseed meal
Salt
Total
Dig. protein, 21.2%
Total dig. nutrients, 74.1%

3. Ground corn
Ground oats
Wheat bran
Corn gluten feed
Soybean oil meal (or cot
seed meal)
Cane molasses
Salt
Total
Dig. protein, 21.2%
Total dig. nutrients, 72.0%

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cent protein
.... 880 lbs.
.... 500 lbs.
.... 200 lbs.
feed .... 300 lbs.
meal (or cotton-
) .... 300 lbs.
.... 20 lbs.
.... 2,000 lbs.
15.5%
trients, 74.3%

.... 540 lbs.
.... 500 lbs.
.... 200 lbs.
il .... 370 lbs.
feed .... 370 lbs.
.... 20 lbs.
.... 2,000 lbs.
, 15.1%
itrients, 73.5%

in sorghum ...... 1,045 lbs.
.... 300 lbs.
.... 200 lbs.
meal (or soybean
.... 435 lbs.
.... 20 lbs.
.... 2,000 lbs.
, 14.4%
utrients, 74.5%

ob meal .... 970 lbs.
.... 450 lbs.
meal (or soybean
.... 280 lbs.
al .... 280 lbs.
.... 20 lbs.
.... 2,000 lbs.
, 14.5%
utrients, 71.1%

Add 20 lbs. ground limestone
ient in calcium.)

rn .... 660 lbs.
s .... 400 lbs.
n .... 200 lbs.
l meal .... 370 lbs.
ried corn grains ... 380 lbs.
.... 20 lbs.
.... 2,000 lbs.
, 16.7%
utrients, 76.4%

n .... 510 lbs.
ts .... 300 lbs.
n .... 200 lbs.
eal .... 470 lbs.
n feed .... 500 lbs.
.... 20 lbs.
.... 2,000 lbs.
n, 16.9%
nutrients, 76.0%

3. Ground barley .... 915 lbs.
Ground oats .... 400 lbs.
Wheat bran .... 200 lbs.
Soybean oil meal (or cottonseed meal) .... 465 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 17.6%
Total dig. nutrients, 74.4%

4. Ground corn .... 430 lbs.
Ground oats .... 300 lbs.
Wheat bran .... 200 lbs.
Corn gluten feed .... 450 lbs.
Soybean oil meal .... 400 lbs.
Cane molasses .... 200 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 17.4%
Total dig. nutrients, 72.1%

5. Ground grain sorghum .... 900 lbs.
Ground oats .... 300 lbs.
Wheat bran .... 200 lbs.
Cottonseed meal (or soybean oil meal) .... 580 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 16.8%
Total dig. nutrients, 74.0%

6. Corn-and-cob meal .... 870 lbs.
Wheat bran .... 400 lbs.
Cottonseed meal (or soybean oil meal) .... 353 lbs.
Linseed meal .... 355 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 16.9%
Total dig. nutrients, 71.3%

G. Mixtures containing approximately 24 per cent protein (Add 20 lbs. of ground limestone per ton if roughage is grown on soil very deficient in calcium.)

For cows in milk which are fed good-quality non-legume roughage and which are not producing sufficient milk to require so much as 8 lbs. of concentrate or grain mixture.

For cows in milk which are fed only non-legume roughage of fair to poor quality.

1. Ground corn .... 380 lbs.
Ground oats .... 300 lbs.
Wheat bran .... 200 lbs.
Soybean oil meal (or cottonseed meal) .... 500 lbs.
Distillers dried corn grains ... 600 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 20.2%
Total dig. nutrients, 77.1%

2. Ground barley .... 580 lbs.
Ground oats .... 400 lbs.
Wheat bran .... 200 lbs.
Soybean oil meal (or cottonseed meal) .... 500 lbs.
Linseed meal .... 300 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 21.2%
Total dig. nutrients, 74.1%

3. Ground corn .... 220 lbs.
Ground oats .... 200 lbs.
Wheat bran .... 200 lbs.
Corn gluten feed .... 600 lbs.
Soybean oil meal (or cottonseed meal) .... 560 lbs.
Cane molasses .... 200 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 21.2%
Total dig. nutrients, 72.0%

4. Ground corn .... 380 lbs.
Ground oats .... 200 lbs.
Wheat bran .... 200 lbs.
Linseed meal .... 500 lbs.
Corn gluten feed .... 500 lbs.
Soybean oil meal .... 200 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 20.7%
Total dig. nutrients, 74.1%

5. Ground grain sorghum .... 680 lbs.
Ground oats .... 300 lbs.
Wheat bran .... 200 lbs.
Cottonseed meal .... 500 lbs.
Soybean oil meal .... 300 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 20.2%
Total dig. nutrients, 74.0%

6. Corn-and-cob meal .... 620 lbs.
Wheat bran .... 400 lbs.
Cottonseed meal (or soybean oil meal) .... 500 lbs.
Linseed meal .... 460 lbs.
Salt .... 20 lbs.
Total .... 2,000 lbs.
Dig. protein, 19.7%
Total dig. nutrients, 71.3%

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l. Those hybrids
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composition by changing the amylose-amylopectin ratio (i.e., the ratio of straight-chain versus branched molecules). Among these are dull (*du*) and sugary-2 (*su2*). Both of these genes have been studied in combination with *wx* and *ae* (Alexander and Creech, 1977), but commercial usage of these gene combinations has not developed.

Both waxy and high-amylose hybrids are grown under contract for corn wet-milling. Since both genes are recessive, the fields in which they are produced must be isolated from normal dent corn. Limited acreages of waxy corn are also grown as feed for cattle and other livestock. Discussion of the products made from waxy and high-amylose corn starches is covered in Chapter 16.

PROTEIN MODIFICATION

Several endosperm mutants that alter the balance of amino acids have been identified. The most important of these is opaque-2 (o_2). Mertz et al (1964) reported that o_2 reduced zein in the endosperm and increased lysine. Other mutant genes with similar effects are floury-2 (fl_2) and opaque-7 (o_7).

Kernels with the o_2 gene are characterized by a soft, chalky, nontransparent appearance, with very little hard vitreous or horny endosperm. This type of kernel is more prone to damage by kernel rots, insects, rodents, and harvesting machinery. Much improvement has been made in increasing resistance to ear and kernel rots by selection for more vitreous o_2 types (CIMMYT, 1982). However, lysine levels tend to decrease, so selection must be accompanied by chemical endosperm analysis to retain high levels of lysine.

Yields of the first o_2 hybrids were 85–90% of those of the normal dents. However, through selection, the yields of modified o_2 material have been improved during the last decade.

High-lysine corn can be an important source for a balanced protein in the diets of nonruminants. Several nutritional studies have shown the potential value of high-lysine corn in helping meet human food needs in the less developed countries. In the United States, the use of high-lysine corn has been restricted because it yields less than normal dent corn and because a nutritionally balanced protein from corn is not needed when soybean (*Glycine max*) meal is readily available. The trade-off in growing high-lysine corn is that of losing calories per hectare in exchange for a gain in higher quality protein.

B. Altering Kernel Composition and Integrity by Selection

OIL

The oil content of hybrids from the U.S. Corn Belt ranges from 3.5 to 6.0%, with an average of about 4.5%. The long-time Illinois selection experiment (Dudley and Lambert, 1974) showed that oil content can go from as low as 0.1% to as high as 19.6%. Development of wide-line nuclear magnetic resonance spectroscopy has given researchers a nondestructive, rapid method of determining the oil content of samples as small as an individual kernel (Bauman et al, 1965). High-oil hybrids, with greater than 6% oil content, are lower in yield than hybrids with less than 6% oil. Increasing oil content genetically is not a difficult task, because variation occurs in existing germ plasm and most of it is heritable (Alexander and Creech, 1977).

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Oil quality is a function of the relative amounts of unsaturated and saturated fatty acids. Oils with a high proportion of linoleic acid and lesser amount of oleic, palmitic, and stearic acids are desired and often recommended for human diets. The linoleic acid content of oil in commercial corn produced in the United States before 1964 averaged 58.7%, but by 1968, it had increased to 61.9%. Corn inbreds vary significantly in linoleic acid. Alexander and Creech (1977) found that 169 inbred lines from the northern U.S. Corn Belt averaged 58%, whereas 63 inbred lines from the southern United States averaged 48%. The amount of fatty acids is under genetic control and can be altered through breeding (see Chapter 10).

PROTEIN QUANTITY

Protein quantity in corn grain is a function of cultural practices and heredity. The current average protein content of U.S. hybrids ranges between 9 and 11% (moisture-free basis). Through selection, protein content can be altered. The long-time Illinois selection experiment covering 70 generations of selection for protein has produced corn with a low of 4.4% and corn with a high of 26.6% (Dudley and Lambert, 1974). Currently, not much interest exists in developing hybrids with higher protein potential because economically available soybean protein can produce a ration that is balanced with respect to the essential amino acids.

KERNEL INTEGRITY

Damage to kernels during harvesting, drying, elevating, and moving grain through commercial channels has become of great concern, especially to the export trade. Contributing to the problem has been the change from harvesting on the ear to using field picker-shellers. No artificial drying was needed for corn harvested on the ear, as it dried naturally in a storage crib. Because one of the advantages of combine harvesters is relatively earlier harvesting to reduce field losses, the grain usually has a high moisture content and requires artificial drying. Due to limited drying capacity, most farmers dry grain rapidly at high temperatures, often in excess of 80° C. Excessively rapid removal of moisture causes stress cracks to occur in the kernels. When the grain is moved through market channels, kernels hit hard objects that cause them to break, resulting in fine particles that lower the value of the product.

Research focused on solving the corn breakage problem is being coordinated through regional project NC-151.[1] Methods of determining breakage susceptibility have been developed (Chapter 5), which have been used to show that many kernel characteristics are related to the breakage problem. Some of these characteristics are 1) the ratio of vitreous to nonvitreous endosperm, 2) kernel density, 3) average kernel weight, 4) pericarp quantity and quality, 5) test weight, and 6) kernel size and shape. Most of these characteristics are heritable, but at this time, corn breeders have not given high priority to selection for kernel breakage reduction, as no reward is given the farmer for improved grain quality.

Kernel integrity can be measured by subjecting a sample of the corn lot to be tested to mechanical breakage in a machine designed for that purpose (Chapter 5). The Stein Breakage Tester (SBT) has been widely used in testing corn for

[1]North Central Regional Research Project NC-151, Marketing and delivery of quality cereals and oilseeds in domestic and foreign markets. Ohio Agricultural Research and Development Center, Wooster.

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between the oil contents and variations in temperature, rainfall, or fertilization rates were found.

Welch (1969) found that the addition of each of the fertilizer elements N, P, and K increased the oil content of the grain slightly, but the most important effect was the increased grain yield, which produced more oil per unit of land area. Jellum et al (1973) observed that increasing rates of N increased protein percentages but had no effect on oil percentage or fatty acid composition of the oil. In the same study, boron fertilization had no effect on protein or oil content. Genter et al (1956) found that N, P, and K all increased yield but had no appreciable effect on the percentage of oil in corn grain. The corn hybrids were a more important source of variation in oil percentage than were fertilizer, location, or rate of planting. Jellum and Marion (1966) also established that genetic factors had a greater influence on oil content than did environmental factors such as planting dates, location, and year.

Eleven different herbicides have been tested singly and in combinations for their effects on corn oil quantity and composition (Penner and Meggitt, 1974; Wilkinson and Hardcastle, 1973, 1974). None of the treatments, whether incorporated before planting or applied pre- or postemergence, affected oil percentage. When effects on fatty acid composition were noted, the changes were minor. Competition from failure to control weeds did not alter oil content or fatty acid composition.

Severe weather and disease may lower the oil content of corn grain. When corn plants were subjected during grain fill to drought that reduced kernel weight to 52% of that of the control (Jurgens et al, 1978), the drought increased the protein content of the grain from 8.3 to 11.0% but decreased the oil content from 3.8 to 3.1%. In 1970, when an epidemic of southern corn leaf blight (*Helminthosporium maydis*) occurred, no effect was noted on the starch and protein content of the grain, but oil content was reduced essentially in proportion to the amount of blight damage (Freeman, 1973).

B. Genetic Control of Oil Content

Oil content is a highly heritable trait in corn. The classic experiment in breeding corn for high and low oil contents was started at the University of Illinois in 1896 and is still being conducted (Dudley, 1974, 1977). The original Burr's White corn had 4.7% oil. In 1984 after 85 generations of mass selection among ears for high and low oil contents, the IHO strain had 20.4% oil and the ILO strain 0.3% oil (J. W. Dudley, personal communication). An important finding from this long-term experiment is that significant variability for oil still exists in the IHO strain (Dudley, 1977) and further increases in oil should occur as selection is continued. Both germ size and oil percentage in the germ have increased in IHO, but endosperm and total grain weight have decreased (Curtis et al, 1968). With selection only for oil, the yield of IHO has fallen to about 30% of that of commercial hybrids.

A significant development in breeding for higher-oil corn has been the adaptation of wide-line nuclear magnetic resonance (NMR) spectroscopy to nondestructive analysis of oil content in corn grain (Bauman et al, 1963; Alexander et al, 1967; Watson and Freeman, 1975). Large numbers of samples can be screened because the scan time may be as brief as 2 sec. Single-kernel

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NMR screening and recurrent selection have facilitated the development of populations with higher oil. D. E. Alexander (Univ. of Illinois, Urbana, personal communication) has achieved an increase in oil content in Alexho Synthetic from 4.4 to 16.4% in only 23 cycles, a gain of about 0.5% per year. IHO, in the long-term experiment originally based on mass selection among ears and destructive chemical analysis for oil, has shown an increase of only 0.17% per year. Using high intensity selection by NMR within half-sib families, Miller et al (1981) were able to increase the oil content of Reid Yellow Dent corn from 4.0 to 9.1% in only seven cycles and with no reduction in yield.

Interest in breeding higher-oil corn is worldwide. Trifunović et al (1975) at the Maize Research Institute in Yugoslavia have used NMR analysis to develop lines that vary in oil content. Among 490 inbred lines from their breeding program, the oil content ranged from 2.7 to 12.5% with a mean value of 6.1%. Lico (1982) has isolated inbred lines from native populations in Albania that show promise for breeding hybrids with higher oil contents. In Iraq, Baktash et al (1982), using five cycles of modified mass selection from a synthetic corn variety Neelum, increased oil content 0.17% per cycle.

Alexander (1982) has released three high-oil inbreds to the seed trade (R802A—7% oil, R805—9%, and R806—9%). A commercial hybrid with 6.5–7.0% oil is now being marketed to U.S. farmers. Additional hybrids are being selected at the University of Illinois for 6–8.5% oil content and yields equivalent to those of commercial varieties. For example, R806 × B73 (6.7% oil) gave the same average yield (9.34 t/ha; 149 bu/acre) as the well-known hybrid Mo17 × B73 (4.3% oil) over a six-year period, 1979–1984 (Alexander, 1986). Higher-oil hybrids that yield as much grain per hectare as commercial hybrids will produce more energy (calories) per hectare. The energy content of oil is 37.7 J/g (9 kcal/g); that of protein or carbohydrate is only 16.8 J/g (4 kcal/g).

Significant positive correlations between oil content and yield components have not been found consistently. Raman et al (1983) examined correlations among oil percentage and yield components in a study with 27 inbred lines and three testers in a line-by-tester design. Oil content was positively correlated with grain yield, plant height, ear height, ear length, number of kernels per row, moisture content, and 100-kernel weight, but the correlations were significant only for 100-kernel weight and grain yield. Alexander and Seif (1963) found no correlation between 100-kernel weight and oil content.

The oil percentage of a corn kernel can be increased by a larger germ size, higher percentage of oil in the germ, or a smaller endosperm. Some endosperm mutants such as brittle-2, floury-2, and sugary-2 have higher oil percentages than does conventional corn, but the increase is due mainly to reduced endosperm size (Flora and Wiley, 1972; Arnold et al, 1974; Roundy, 1976).

Opaque-2 kernels tend to have larger ratios of embryo to endosperm than conventional corn does (Arnold et al, 1974; Valois et al, 1983). Eggum et al (1983) have developed four opaque-2 hybrids with 5.8–6.5% oil (Table I). Although the grain yields of the opaque hybrids were all lower than that of the conventional corn, the oil yields per hectare were higher for three of the four opaque types. The waxy corn with 5.6% oil also yielded more oil per hectare than the conventional corn with 5.1% oil. The highest grain yield in this study was attained by a high-oil hybrid (5.5% oil), but the authors cautioned that the grain yields were calculated from yields obtained in small field plots. All of the high-oil

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A feeding trial
Adams and Jensen
oil corn with 7.5%
(Table II). The ex

Compositions and

Hybrid ZPSC	Type
704	Conventio
071	Opaque
073	Opaque
074	Opaque
076	Opaque
757	Waxy
780	Waxy
781	High-oil
727	High-oil
717	High-oil
747	High-oil

[a]Adapted from Eggum
[b]Nitrogen × 6.25.
[c]Determined from rat f

Perf

Average d
Average d
Average g

[a]From Ad
[b]Diet I, co
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soybean n
16.8 MJ/
(24.64%)
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corns showed more utilizable protein in rat feeding trials than did the conventional corn.

C. Value of High-Oil Corn in Animal Feeding

A feeding trial of high-oil corn in growing-finishing pigs was reported by Adams and Jensen (1981). These researchers compared the utilization of high-oil corn with 7.5% oil (Diet II) to that of conventional corn with 3.5% oil (Diet I) (Table II). The experiment was also designed to test whether the oil in intact

TABLE I
Compositions and Yields of Conventional Corn and Opaque, Waxy, and High-Oil Corns[a]

				Yield			
Hybrid ZPSC	Type	Oil (%)	Protein[b] (%)	Grain (t/ha)	Oil (kg/ha)	Utilizable[c] Protein (kg/ha)	Lysine (kg/ha)
704	Conventional	5.1	9.6	14.3	733	805	42.0
071	Opaque	5.8	9.0	11.4	659	792	39.5
073	Opaque	5.9	10.9	14.0	823	1,085	60.7
074	Opaque	6.1	8.6	13.6	832	921	49.9
076	Opaque	6.5	8.9	11.7	762	788	44.0
757	Waxy	4.8	9.6	13.3	645	817	39.1
780	Waxy	5.6	8.9	13.9	774	845	38.3
781	High-oil	5.2	10.4	12.8	660	857	34.2
727	High-oil	5.5	11.9	15.5	855	1,071	49.7
717	High-oil	7.1	10.9	13.8	981	891	41.9
747	High-oil	8.2	12.5	12.0	982	836	37.3

[a]Adapted from Eggum et al (1983). All values on dry weight basis.
[b]Nitrogen × 6.25.
[c]Determined from rat feeding assays.

TABLE II
Performance of Growing-Finishing Pigs on Diets Containing Conventional and High-Oil Corns[a]

	Diets[b]		
	I Conventional Corn (3.5% oil)[c]	II High-Oil Corn (7.5% oil)[c]	III Conventional Corn + Corn Oil
Average daily gain, kg[d]	0.84	0.85	0.82
Average daily feed, kg[e]	1.67 a	1.55 b	1.56 b
Average gain/feed[e]	0.50 a	0.55 b	0.53 b

[a]From Adams and Jensen (1981).
[b]Diet I, conventional corn (73.89%) + soybean meal (23.46%) + vitamins and minerals (2.65%), 16.5 MJ/kg. Diet II, high-oil corn (73.74%) + soybean meal (23.60%) + lysine (0.01%) + vitamins and minerals (2.65%), 16.8 MJ/kg. Diet III, conventional corn (71.32%) + soybean meal (24.64%) + corn oil (1.39%) + vitamins and minerals (2.65%), 16.8 MJ/kg.
[c]Oil content expressed on "as is" basis.
[d]Each value is an average for three pens of eight pigs each.
[e]Values in the same row followed by different letters are significantly different ($P < 0.05$).

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high-oil corn grain was used as efficiently as added oil. A diet (Diet III), isocaloric with Diet II, was prepared by adding corn oil to conventional corn. In all the diets, crude protein and lysine levels were above suggested requirements to ensure that neither would be nutritionally limiting. No significant differences in average daily gain were observed among the dietary treatments, but the daily feed intakes for the high-oil corn diet and for the conventional corn plus corn oil diet were significantly lower than for the conventional corn diet. The average gain/feed values for both the high-oil diets were similar and were significantly higher than for the conventional corn diet, indicating that the pigs used the intact high-oil grain efficiently. Feeding supplemental calories as higher oil in intact seeds would eliminate the handling, storing, and mixing problems that are associated with the addition of oils or fats to feedstuffs.

In an earlier experiment, Nordstrom et al (1972) fed 7% oil corn to growing-finishing pigs and found that 5–6% less high-oil corn than conventional corn was required per kilogram of gain. The 7% oil corn had little effect on pork quality, but diets containing 15% oil through addition of corn oil produced soft and oily carcasses that were unacceptable for conventional processing. The quality of the pork carcasses was affected by the additional oil in the diet and also by the greater polyunsaturation of the 15% oil diet (62% linoleic acid) compared to that of the high-oil corn diet (51.7% linoleic acid).

Han and Parsons (1984) have compared the nutritional value for poultry of a commercial, high-oil corn hybrid (5.7% oil, 9.5% crude protein, 14% moisture) relative to that of conventional corn (3.6% oil, 8.5% crude protein, 14% moisture). Laying hens fed 17% protein diets containing high-oil corn had significantly better egg-to-feed (wt/wt) ratios and higher body weight gains than hens fed conventional corn, regardless of whether the high-oil corn was substituted on an equal weight or an isonitrogenous basis. No differences between corn types were found for egg production, egg weight, feed consumption, and egg yield (grams per hen per day). Broiler chicks fed the high-oil diet from 8 to 22 days posthatching had improved gain/feed ratios compared to those fed the same diet containing conventional corn. The true metabolizable energy of high-oil corn was found to be 4.5% higher than that of conventional corn in a study involving adult roosters.

The nutritive value of high-oil corn for chickens has also been investigated in Yugoslavia (S. Savić, M. Latkovska, and B. Supić, personal communication). One-day old, male chicks were fed diets containing conventional corn (4% oil) or a high-oil corn hybrid (7.9% oil). After 56 days, the control group had gained 952 g and the high-oil group 1,006 g; the difference was statistically significant ($P<0.05$). Feed conversion per kilogram gain was 2.58 for the high-oil corn and 2.75 kg for the conventional corn.

III. FATTY ACID COMPOSITION

The structures of the fatty acids found in corn oil and other vegetable oils are shown in Fig. 1. The zigzag conformation of the hydrocarbon chains and the natural *cis* configuration of the double bonds are indicated. The pathway for the biosynthesis of the fatty acids (Stumpf, 1980) is also shown.

A major selling point for corn oil is its high level of the essential, polyunsaturated fatty acid, linoleic acid (18:2). Consumers have been made

aware of the impor
Corn oil is an excell
very stable oil becai
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Among the comn
sunflower oil (69.5%
than corn oil (61.9%
soybean oil, has a lo
higher content (6.8
susceptible to oxidat
Corn oil has low l
and stearic acid (18:
25.2%) and palm (16:
(14:0), palmitoleic (

Fig. 1. Chemical structures

	Fatty
Oil	16
Safflower	6
Sunflower	(
Corn	11
Cottonseed	25
Soybean	10
Palm	44

[a]Fatty acids are identified ...
palmitic acid, 16:0; stearic ...
[b]No value given.

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CHAPTER 11

CORN DRY MILLING: PROCESSES, PRODUCTS, AND APPLICATIONS

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I. INTRODUCTION

A. History of Corn Dry Milling

The history of corn milling follows very closely the history of corn development, which most experts agree originated in North America; corn was probably not introduced into Europe until after Columbus discovered the New World. This history goes back several thousand years, as recorded by several investigators. Mangelsdorf and co-workers (1964) reported the discovery of 7,000-year-old plant remains, which they identified as a wild progenitor of modern corn. Over 20,000 specimens of corn, about half intact cobs, have been found in several caves in both the Tehuacan valley of Mexico and the southwestern United States. These corn samples have been dated between 4,000 and 6,500 years old (Mangelsdorf et al, 1967; Mangelsdorf, 1974).

In addition to fossil corn, artifacts used with corn have been found. Belt (1928) observed that the ancient Indians of Nicaragua buried the stones they had used for grinding corn along with their dead. Undoubtedly, these stones were considered indispensable for the person's future life. They were essentially the first rudimentary means of milling corn.

For a look at the key developments of early corn dry milling, one can examine the implements used in pioneer America. Initially, the early settlers adopted the use of the Indian metate, which was only a slight improvement over the early grinding stones. With this device, the corn was ground between a hand-held stone and a concave bedstone.

One step up from the metate was the hominy block. Early directions for making this device were quite simple, as recorded by Hardeman (1981):

> Near the cabin cut off a hardwood tree three or four feet above the ground and hollow out the top. From a springy limb of another tree extending over the stump, tie a pestle or block of wood by a strong line.

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The hominy block was operated by repeatedly plunging the wood pestle into the hollow stump until the corn had been sufficiently crushed into meal.

The hominy block was eventually replaced by a single-family, stone device called a quern (pronounced kwern). This was a small, burred-stone grinding apparatus, apparently invented in ancient Rome. It was operated by pouring corn through the cone-shaped axle hole at the top. An off-set handle was used to rotate the capstone on the stationary "netherstone," and the cornmeal worked out between the stones and fell into a tub surrounding the quern.

The principle of this type of revolving stone mill was applied on a much larger scale as early as 1620 (Hardeman, 1981). It expanded to become the local grist mill, which was eventually used to process both corn and wheat. Energy to operate the mill was supplied by livestock, occasionally by humans and by water. By the mid-1800s, most of the mills in the United States were operated by water, although steam-driven mills were used in some sections of the country.

A number of grist mills are still used to grind corn today, particularly in the southern states (Larsen, 1959). As in pioneer America, the mills are relatively small, and finished product distribution is limited to a small geographic area. These milling systems have gradually given way to the more sophisticated tempering-degerming systems, which were introduced in the early 1900s.

B. Present Milling Capacity in the United States

According to Brekke (1970a), as of 1965 there were 152 dry corn mills in the United States with a daily capacity of 50 cwt (2.27 t) or more. By 1969 this number had dropped to 115. More recent statistics (Anonymous, 1984b)

TABLE I
Principal Corn Dry-Milling Companies: Plant Locations and Estimated Mill Capacities[a]

Company	Mill Location	Estimated Daily Capacity (1,000 bu)[b]
Archer Daniels Midland	Lincoln, NE (Gooch Mills)	15
Evans Milling Co.	Indianapolis, IN	30
Illinois Cereal Mills Inc.	Paris, IL	65
Krause Milling Co.	Milwaukee, WI	55
Lauhoff Grain Co.	Danville, IL	70[c]
	Crete, NE (Crete Mills)	50
Lincoln Grain, Inc.	Atchison, KS	45[d]
Martha White Foods[e]	Nashville, TN	25
Midstate Mills, Inc.	Newton, NC	15
The Quaker Oats Co.	Cedar Rapids, IA	20
	Chattanooga, TN	15
	St. Joseph, MO	10
J. R. Short Milling Co.	Kankakee, IL	30
Total		445

[a] With the exception of two companies, the figures are based on unpublished data.
[b] Multiply the figures in this column by 39.4 to convert to metric tons.
[c] Anonymous (1978).
[d] Anonymous (1984a).
[e] Headquarters in Nashville, TN, with five separate mills: three in Tennessee, one in Georgia, and one in West Virginia.

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in 1984. Of this total, 66
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Indications are that onl
corn processed by the indu:
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II. TEMP

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discussions, flow charts, et
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the size of the mill.
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imated Mill Capacities[a]

Estimated Daily Capacity (1,000 bu)[b]
15
30
65
55
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50
45[c]
25
15
20
15
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30
445

ıblished data.
s.

Tennessee, one in Georgia,

suggests that the decline in dry mills has tapered off, with 88 mills still operating in 1984. Of this total, 66 are smaller mills located in the southern states and California (two), with most of the remaining mills (20) in the Midwest.

Indications are that only 17 of the dry-milling plants account for most of the corn processed by the industry. A list of the principal milling companies is shown in Table I. Of the 17 mills, at least 12 are fairly large operations having daily capacities of between 10,000 and 70,000 bu (250–1,750 t) and utilizing tempering-degerming processes. Ten of the mills are located in the Midwest, and five are relatively small plants in the South.

The total of 445,000 bu (11.1×10^3 t) of corn per day (from Table I) corresponds to an annual volume of about 111 million bushels (2.77×10^6 t). This represents 92% of the corn processed by the whole industry for the 1977/1978 crop year (Anonymous, 1982) and indicates that most of the corn processed by dry millers in this country today is processed by the larger-capacity, tempering-degerming systems.

II. TEMPERING-DEGERMING SYSTEMS

A. Process with the Beall Degerminator

The Beall degerminator, introduced in 1906 (Larsen, 1959), set the stage for the development and production of refined dry-milled corn products. Although other types of degerminating equipment have been introduced since 1906, the Beall machine has remained the mainstay for most U.S. companies employing tempering-degerming systems. It has allowed the dry-milling industry to move from numerous small, locally operated grist mills with limited capacity and distribution to larger, more efficient plants processing 20,000–70,000 bu (500–1,750 t) per day with nationwide distribution. It has also allowed for the production of higher-quality, low-oil, essentially germ- and bran-free endosperm-based products with greatly extended shelf life and product stability.

Probably the major reference work cited by most of the recent authors in the field is that of Stiver (1955). This work describes the processes and equipment used by the corn dry millers in very detailed fashion, as do the more recent reviews by Brekke (1970a) and Anderson and Watson (1982). Their excellent discussions, flow charts, etc., are not reproduced here. However, the key aspects of the process are briefly reviewed to provide the reader sufficient background to the subsequent sections of this chapter.

As shown in the flow chart in Fig. 1, shelled, whole U.S. No. 2 yellow corn is received and placed in storage in standard corn silos. Today most of the corn is delivered by truck or railcar directly to the corn mills from country elevators or individual farms. Most corn mills have one to two weeks of storage capacity, which could amount to well over one million bushels (25×10^3 t), depending on the size of the mill.

The corn is first dry cleaned, which includes passage under a magnet (positioned over a belt conveyor) to remove tramp metal, aspiration to remove fines and pieces of cob, and screening to separate whole corn from broken corn. The desire is to have only whole kernels entering the corn mill. After wet cleaning to remove surface dirt, dust, rodent excreta, etc., the corn is adjusted to about

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20% moisture and placed in a tempering bin. Optimum tempering moisture and times have been reported by Brekke and co-workers (Brekke et al, 1961, 1963; Brekke and Weinecke, 1964; Brekke, 1966, 1967, 1968, 1970a, 1970b; Brekke and Kwolek, 1969).

The product is then processed in the Beall degerminator, in which the whole moist corn is essentially treated by an abrading action to strip the bran or pericarp and germ away from the endosperm while leaving the endosperm intact. The most efficient way to operate the degerminator has been reported by Brekke et al (1961, 1963), Brekke and Weinecke (1964), and Weinecke et al (1963). This is obviously an ideal picture of what the corn miller would like to have happen. In fact, some of the bran and germ remain attached to the endosperm and must be removed in subsequent aspiration and milling processes. Also, some of the endosperm remains associated with the bran and germ fractions, all of which are separated by subsequent use of aspirators and gravity tables.

Let us assume that most of the endosperm is separated from bran and germ. The Beall is set up so that the large pieces of endosperm, known as "tail hominy," proceed through the end of the degerminator. This fraction is dried, cooled, and sifted, and part of it is isolated as large flaking grits. (The conditions for obtaining maximum yield of flaking grits have been reported by Brekke [1966, 1967] and Brekke and Kwolek [1969]). The remainder is sent to the roller mills for reduction into smaller fractions, such as coarse, medium, or fine grits; meals; or flours. The bran and germ fractions (together) pass through a screen on the underside of the degerminator and become the "thru stock" stream. This stream

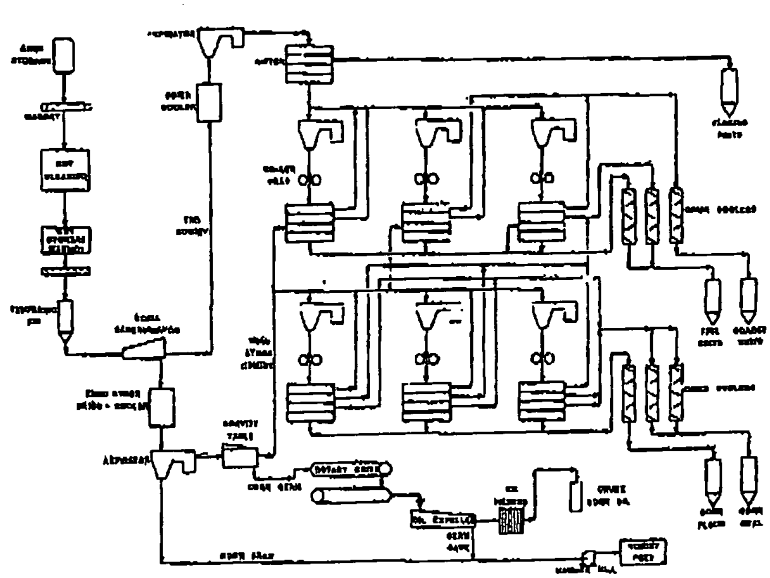

Fig. 1. Production flow chart for a typical corn tempering-degerming system.

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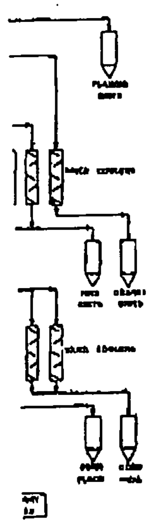

is dried, cooled, aspirated to remove the bran, and processed on gravity tables to separate germ and endosperm.

The germ can then be expelled or hexane-extracted to remove the oil, and the spent germ or germ cake becomes one of the by-product streams. (Some of the corn dry millers do not further process the germ but sell it to other companies that do). The fines separated from the thru stock endosperm are usually high in oil, fine fiber, and tip caps; they become one of the by-product streams known as "standard meal." The bran, germ cake, standard meal, and broken corn (isolated from whole corn before entering the corn mill) are combined, dried, and ground up together to become the main by-product of the corn dry millers, which is known as "hominy feed." Since none of the dry millers refine corn oil, the crude oil obtained from either expelling or extraction is sold to one of several oil refiners in the United States. The main portion of the endosperm isolated from the thru stock is processed in the same way as the tail hominy fraction to produce prime grits, meals, and flours.

As indicated by Stiver (1955) and others, after the degerminator, the roller mills and sifters are the core of the corn milling system. The larger pieces of corn endosperm are sent to a series of roller mills, where they pass between sets of corrugated rolls; the corrugations vary in size, depending on the level of particle size reduction required. The ground endosperm stream proceeds to the sifters, which can separate the mixture into as many as 16 different fractions.

The larger-sized particles can be sent to another set of rolls for further reduction, or combined with other streams of similar particle size, aspirated, dried, cooled, and sent to a finished product bin. Similarly, the medium-sized and small-sized particles may be further milled and sifted and streams of similar size combined to give finished corn grits, meals, and flours of uniform composition.

In several of the major corn dry-milling plants, corn grits and/or flours are further processed in acid modification systems, in extrusion-cookers, or the like, to provide a wider variety of modified corn products for both food and nonfood use. These specialty products are discussed in more detail in several subsequent sections of this chapter.

B. Alternative Milling Systems

At least two alternative dry-milling systems can be employed to produce refined dry-milled corn products (Brekke, 1970a). They have been described as the Miag process, now more correctly the Buhler-Miag process (Wyss, 1974), and the Ocrim process. Both of these systems were developed in Europe and have been used to some extent throughout the world. Selected pieces of equipment from the two systems have also been incorporated into several corn mills in this country. Since the systems have been discussed in detail by Brekke (1970a), no further description is given here.

III. DRY-MILLED PRODUCTS—TYPES, VOLUMES, AND COMPOSITION

The primary products derived from the tempering-degerming process are corn grits, cornmeals, and corn flours. An infinite number of products are possible as

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the result of particle size reduction on the roller mills, from flaking grits as coarse as four- to six-mesh down to fine-grind corn flour with 95% passing through a 100-mesh sieve. However, most of the products can be classified into one of the six main groups shown in Table II.

At one time, brewer's grits, in particular, included numerous products covering the particle size range from 10–12 mesh grits to cornmeal. In the brewing process, the size of the particulate material remaining after cooking and enzymatic hydrolysis of the corn adjunct has a definite impact on the manner in which the hydrolyzed starch liquor, known as "wort," filters. The nature of this residual, high-protein material appears to be unique to the particular type of brewing equipment and process employed. Otherwise, essentially no differences in composition are found between coarse, regular, and fine grits.

This is also true of all products coming from the main portion of the corn endosperm, including flaking grits, coarse or fine brewer's grits, or corn cones—a very fine, uniform cornmeal. The composition of these materials is shown in Table III. Typically they contain 7–8% protein, less than 1% fat, ash, or fiber, and 77–79% starch (88–90%, dry basis).

The only material that varies somewhat in composition, is corn flour, particularly that produced during normal roller milling of large grits to smaller

TABLE II
Typical Products of the Corn Tempering-Degerming System: Granulations and Product Volumes[a]

	Particle Size						
	From			To			
		Size			Size		
Product	Standard U.S. Mesh	in.	μm	Standard U.S. Mesh	in.	μm	Annual Volume[b] (million lb)
Flaking grits	−3.5	−0.223	−5,600	+6	+0.132	+3,350	750
Coarse grits	−10	−0.0787	−2,000	+15	+0.0512	+1,290	940
Regular grits	−15	−0.0512	−1,290	+30	+0.0234	+600	1,360
Cornmeal	−30	−0.0234	−600	+60	+0.0098	+250	190
Corn cones	−40	−0.0165	−425	+80	+0.0070	+180	190
Corn flour	−60	−0.0098	−250	+325	+0.0017	+45	330

[a] Data taken in part from Alexander (1973) and Brekke (1970a).
[b] Divide figures in this column by 2,205 to convert to million metric tons.

TABLE III
Typical Composition (%, as-is basis) of Dry-Milled Corn Products[a]

Component	Flaking Grits	Coarse or Fine Grits	Corn Cones	Corn Flour
Moisture	11.7	11.5	12.0	13.0
Protein	7.0	7.5	7.9	5.2
Fat	0.6	0.7	0.6	2.0
Crude fiber	0.2	0.2	0.3	0.5
Ash	0.2	0.3	0.3	0.4
Starch	78.3	78.0	77.4	76.4
Other polysaccharides	2.0	1.8	1.5	2.5

[a] Based on unpublished data.

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grits. This fine fraction (−60 mesh) is usually referred to as "break flour." It contains less protein and somewhat more fat than the other prime products. Break flour is derived from the portion of the corn kernel known as the floury endosperm. Corn flour derived from the roller milling of grits, and coming mainly from the horny endosperm, is known as "reduction flour." It has the same composition as the starting corn grits.

IV. INDUSTRIAL APPLICATIONS

A. Current Market Volumes

The principal applications of the products of the corn dry-milling industry are shown in Table IV. These figures were estimated for the calendar year 1977. Most of the figures in Table IV have been corroborated with other published data for that year, as is discussed below.

The total product volume of 6.19 billion pounds (2.81×10^6 t) should be corrected to 6.05 billion pounds (2.74×10^6 t) to account for the noncorn ingredients in fortified corn products. This corrected figure compares fairly well to the 5.87 billion pounds (2.66×10^6 t) calculated from data for the daily plant capacities of the principal dry millers in Table I, using the following equation:

TABLE IV
Estimated 1977 Product Volumes of the Corn Dry-Milling Industry[a]

Application Areas		Quantity (million lb)[b]
Brewing, total		1,850
Food, general		
Breakfast cereals	800	
Mixes (pancake, cookie, muffin, etc.)	100	
Baking	50	
Snack foods	100	
Other foods (breadings, batters, baby foods, etc.)	75	
Total		1,125
Fortified foods (PL480), total		485[c]
Nonfood		
Gypsum board	100	
Building products (particleboard, fiberboard, plywood, etc.)	40	
Pharmaceuticals/fermentation	200	
Foundry binders	90	
Charcoal binders	75	
Other (paper, corrugating, oil well drilling fluids, etc.)	25	
Total		530
Animal feed,[d] total		2,200
Total		6,190

[a] Estimates based on unpublished data.
[b] Divide the figures in these columns by 2205 to convert to million metric tons.
[c] Corn products represent 65–70% of total shipments, or 315–340 million pounds.
[d] Data reported by Alexander (1973).

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Product volume = 445 million bu/day × 55 lb/bu × 250 days × 0.96
(conversion factor[1])
= 5.874 billion lb

It also compares quite well to a figure of 6.39 billion pounds (2.90×10^6 t), which was calculated using the value of 121 million bushels of corn processed in the 1977/1978 crop year, as reported in the 1982 *Commodity Year Book* (Anonymous, 1982).

The product with the largest volume was hominy feed, the chief by-product of the corn dry millers, which is sold for animal feed. The value of 2.2 billion pounds (1.0×10^6 t) was taken from published data (Alexander, 1973), which is in good agreement with the 2.285 billion pounds (1.04×10^6 t) reported by Wells (1979). The second biggest application area is in the brewing industry, where 1.85 billion pounds (0.84×10^6 t) of corn grits and meals were used in brewing adjuncts. This agrees well with a figure of 1.77 billion pounds (0.80×10^6 t) compiled from reports in *The Brewers Digest* (Anonymous, 1974–1984).

The volume of 1.61 billion pounds (0.73×10^6 t) used in food applications (1.125 billion in general foods plus 0.485 billion in fortified foods) is reasonably close to the figure of 2.0 billion pounds (0.91×10^6 t) reported by Brockington (1970).[2] The breakdown in the general food area (Table IV) has not been published before, so no basis for comparison exists. The value of 485 million pounds (0.22×10^6 t) of fortified foods is quite similar to the figures shown in Table VI for the years 1979–1982 (Bookwalter, 1983).

The product volume of 530 million pounds (0.24×10^6 t) for nonfood uses is considerably higher than data previously published by Senti (1965) and Alexander (1973). The larger figure was the result of increases in the use of corn flours in gypsum board, foundry binders, and particularly citric acid production (in the fermentation area) during the 1975–1978 period. According to Wells (1979), this volume dropped off to 377 million pounds (0.17×10^6 t) in 1979, which is probably closer to current usage levels. Specific application areas are discussed in the following sections of this chapter.

B. Brewing

THE BREWING PROCESS

Traditionally, the brewing industry has been the largest user of prime products made by the corn dry millers. A brief description of the process will aid in understanding of the use of corn grits in making beer. When grits are used in brewing beer, the first step is cooking the grits. This is frequently accomplished in the "mashing" or "mash tun" (or tub) before treatment with barley malt. Corn grits and water are combined, heated to 90–95°C to gelatinize the starch, and cooled to 67°C. Alternatively, grits may be processed through a jet cooker or a continuous cooker. Malt is added, and starch from both malt and corn grits is hydrolyzed to fermentable sugars by the joint action of α- and β-amylases. The solubilized carbohydrates are separated from the spent grains by filtering

[1]Factor converting corn with 15% moisture corn to finished products with 11% moisture.

[2]Figure obtained by adding the degermed corn meal (0.75 billion pounds) to grits for human consumption (1.28 billion pounds) (Brockington, 1970, in Table 15.1).

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a form of adjunct with a higher concentration of fermentable sugars. Therefore, increases in brewing capacity (Pfisterer et al, 1978) and production rates (Pollock and Weir, 1976; Swain, 1976) have been possible without plant expansions. Swain (1976) also cited lower production costs, whereas others (Rao and Narasimham, 1975; Pollock and Weir, 1976) have indicated that syrups result in fewer production problems plus a more uniform product with equal or higher quality. Moll and Duteurtre (1976) indicated that, when a new plant is built, lower capital costs are possible with the use of corn syrups.

The increased use of rice has not been as well documented. However, certain rice varieties can provide higher-gravity brews (Stubits and Teng, 1983) and thus increased brewing capacity similar to that for syrups. In addition, the popularity of lower-calorie beers in recent years has resulted in the increased use of enzymes, both amylolytic and debranching. One patent (Line et al, 1982) claims to use malted rice as the source of debranching enzyme as well as of starch.

C. General Food Uses

INTRODUCTION

Combining the application areas of brewing, general food uses, and fortified foods from Table IV, one obtains a total of nearly three and one half billion pounds (1.59×10^6 t). This represents 87% of the prime products sold for all uses, indicating the importance of the food-beverage industry to the dry corn milling industry. Next to brewing, the general food category is the second largest market segment, with over one billion pounds.

In recent years, several reviews have covered food applications of dry-milled corn products; these include Brockington (1970), Bailey,[3] and Wells.[4] Processes for making breakfast cereals were well documented by Matz (1959). In addition, the food area is updated and discussed more thoroughly in Chapter 13. Consequently, food uses are not described here to any great extent. However, because of the importance of extrusion-cooking as a processing tool for the corn dry millers in both food and nonfood areas, some discussion is devoted to this relatively new technology.

EXTRUSION-COOKING PROCESS

Large-volume extrusion-cookers first became available for use in the cereal industry in the late 1950s to early 1960s. Two commercial full-scale units are shown schematically in Figs. 3 and 4. Basically, the process involves feeding a dry or semimoist (15–25% moisture) corn or other cereal product into the hopper end or feed section of an extruder. At this point, the extruder screw and starting material are usually at ambient temperatures, although the mixing chamber shown in Fig. 4 provides a vehicle in which the cereal product can be heated.[5] Also, at this point in the process, the flights of the extruder screw are the

[3] T. Bailey. Functionality and uses of corn flour. Presented to: Central States Section, Am. Assoc. Cereal Chem., St. Louis, MO, Feb. 16–17, 1973.

[4] G. H. Wells. Cereal flours in fabricated foods. Presented to: Symposium: Fabricated Foods. Central States Section, Am. Assoc. Cereal Chem., St. Louis, MO, Jan. 30–Feb. 1, 1975.

[5] O. L. Johnston. Technical and practical processing conditions with single screw cooking extruders. Presented to: International Seminar on Cooking and Extruding Techniques, ZDS Solinger-Grofroth. West Germany, Nov. 27–29, 1978.

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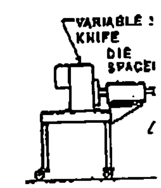

Fig. 3. Cut-away
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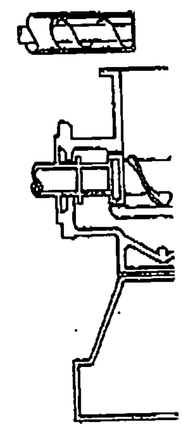

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As the cereal product is moved through the extruder, the temperature in the extruder barrel increases, primarily as a result of 1) the internal shear forces, but also from 2) external heat that can be applied with some extruders, and 3) steam

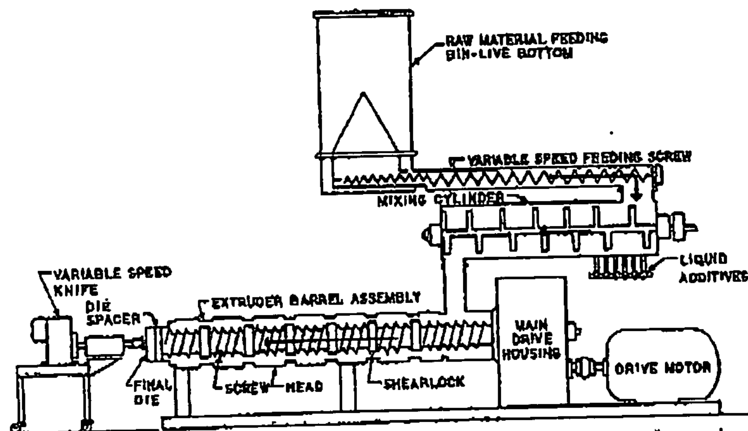

Fig. 3. Cut-away view of a single-screw extrusion-cooker. (Courtesy Anderson International, Strongsville, OH)

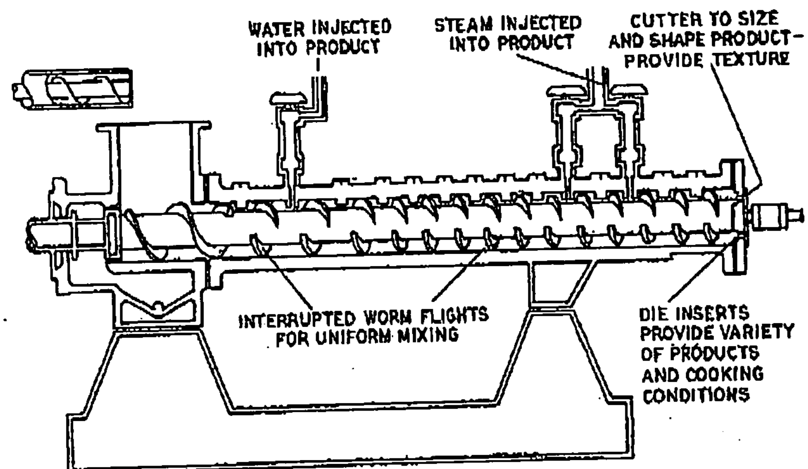

Fig. 4. Cut-away view of a complete extrusion system, including storage bin, screw-conveyor, mixing chamber, and single-screw extrusion-cooker. (Courtesy Wenger Mfg., Sabetha, KS)

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injection that is possible in certain models. The heat causes the starch in the cereal product to gelatinize and swell, and the resulting extrudate becomes quite viscous. This creates additional pressure, shear, and heat at the head end of the extruder barrel.

The extrudate exits the extruder through holes in a die plate. These holes can be varied in size, shape, and number. At the end of the extruder is a variable-speed knife, which cuts the extrudate into smaller pieces called "collets," which are conveyed to a cooler/dryer. If the collets are intended for second- or third-generation snack foods, as defined by Hauck (1980) or Matson (1982), the product is packaged and made ready for shipment. If the final end use is as a precooked cornmeal or corn flour, the dried collets are ground in a hammer mill, entoleter mill, or the like, to the desired particle size before bagging and shipment.

A number of variables in screw design, extruder shape, die configuration, numbers of extruder screws, etc., are possible. For instance, in the machine in Fig. 3, water or other liquids or reagents can be added directly into the extruder barrel, and external heat can be added by steam injection into the barrel. In the machine in Fig. 4, liquid additives are added in the mixing cylinder ahead of the extruder, and part of the heat can be provided through the use of jackets suitable for circulation of water, steam, or other liquid. In addition to the Anderson and Wenger units, single-screw industrial extrusion-cookers are available from Bonnot Company and the Sprout Waldron Division of Koppers and double-screw extruders from Werner-Pleiderer Corporation and Wenger Manufacturing, just to mention a few.

Along with equipment design, cereal properties, such as degree of cooking, density, viscosity, or water absorption properties can be controlled and modified by such process variables as extrusion moisture, temperature, screw speed, and, perhaps most importantly, die configuration. This flexibility has helped make extrusion cooking the important processing tool that it is today in the food industry, and, especially for the corn dry millers, it provides a means of converting corn flour from a by-product into premium products (Roberts, 1967).

EXTRUSION APPLICATIONS

The early patent literature (Bradley and Downhour, 1970; Stickley and Griffith, 1966) describes the use of extruders in producing precooked corn and sorghum flours for use as foundry binders. Subsequent publications reported their use in breadings and croutons (Anonymous, 1983), fabricated foods,[6] fortified cereal products (Anderson et al, 1969, 1970; Bookwalter et al, 1971), and as bases for certain specialty confections and protein-fortified beverages (Hauck, 1980).

The snack food industry seems to have benefited the most from the variety of products, shapes, densities, etc., possible with modern extruders. Cornmeals or corn flours have been found to be particularly useful raw materials (Sanderude, 1969; Matson, 1982) in the production of corn chips (Sanderude, 1969; Scales, 1982; Stauffer, 1983), puffs (Williams, 1977; Toft, 1979; Scales, 1982), onion rings (Sunderude, 1969; Williams, 1977), and several second- and third-generation snacks (Toft, 1979; Hauck, 1980; Matson, 1982). Products made by

[6]See footnote 4.

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direct extrusion compete with snacks made from masa flour, which involves treatment with lye before milling (Scales, 1982; Stauffer, 1983; Przybyla, 1984). Corn processed by the traditional masa process has been recently described by Bedolla and Rooney (1982) and is discussed in more detail in Chapter 13.

D. Corn-Based Fortified Foods

INTRODUCTION

During the late 1950s and early 1960s, a number of changes occurred within the government food aid programs that had a major effect on the corn dry-milling industry. In this period, the shortage of nonfat dry milk (NFDM) resulted in the search for alternate sources of low-cost protein (Senti et al, 1967). The government assisted industry with the passage of the Food for Peace Act of 1966, which broadened the range of commodities eligible for donation to underdeveloped countries. Even before passage of the new legislation, the corn dry millers had developed several corn-based prototypes (Tollefson, 1967), so that in 1966 they were ready to produce the first of several protein-fortified foods.

The first product that received worldwide distribution and acceptance was corn-soy-milk (CSM). The original formula for this material consisted of 64% partially cooked cornmeal (PCM), 24% defatted, toasted soy flour, 5% NFDM, 5% soy oil, and 2% vitamins and minerals. The product was well balanced from a carbohydrate-protein-fat standpoint, and the protein contained a particularly good amino acid profile (Cantor and Roberts, 1967). The combination of corn, soy, and milk proteins resulted in a protein efficiency ratio essentially equivalent to that of casein. It is believed that the combination of functional, flavor, and nutritive properties resulted in the success of CSM.

PURPOSE OF FOOD FOR PEACE PROGRAM

The main objective of the Food For Peace legislation (PL480) has been to provide nutrition, in the form of both total calories and high-quality protein, to the millions of people in the Third World who do not have enough food. Indications are that as many as 10,000 people die each day from malnutrition (Anonymous, 1970), while irreversible physical damage is incurred in thousands more. The emphasis has been directed, in most cases, to weaning and preschool children, in whom protein malnutrition takes its greatest toll.

To accomplish this goal, the various cereal products purchased for the program have been distributed to most of the countries in the world through the Agency for International Development, local governments, and various volunteer agencies, such as CARE, UNICEF, Catholic Relief Agency, and Church World Services. The products get to the people through various programs, including church-related schools, school-lunch programs, and mother-child care centers.

DEVELOPMENT OF CORN-BASED PRODUCTS

In the author's opinion, the development of CSM and the subsequent cereal-based products that have become part of the PL480 program was truly a cooperative effort. It involved industry and government, as represented by the

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U.S. Department of Agriculture and the Agency for International Development, plus a variety of scientists, nutritionists, etc., from private industry, academia, and a variety of government and volunteer agencies. The corn industry (Tollefson, 1967) provided the process capabilities, some of the product development effort (Cantor and Roberts, 1967), and the ability to process and move the large volume of commodity ingredients involved in the manufacture of these products. The U.S. Department of Agriculture was involved in product and process development (Anderson et al, 1969, 1970; Bookwalter et al, 1971; Conway, 1971a, 1971b; Bookwalter, 1977) and in defining specifications and requirements for the products (Senti et al, 1967; Bookwalter et al, 1968, 1971; Bookwalter, 1981).

The corn-based materials developed for PL480, when they were introduced, and their compositions are shown in Table V. Quantities of the products sold to the government from 1970 through 1982 (Bookwalter, 1983) are recorded in Table VI.[7] The size of the figures points up the significant effect this program has had on the corn industry.

Before about 1967, the PCM used to make CSM was generally produced on hot rolls (Anderson, 1982), the commercial products being made on gas-fired rolls. Since 1967, most of the PCM and instant PCM (used to make instant CSM) have been made in extrusion-cookers of the type described in the

[7] R. J. Alexander. Creating new foods from corn and other grains. Presented to: A Workshop on Food Engineering. Texas A&M University, May 19–21, 1975.

TABLE V
Corn-Based Fortified Foods Developed for PL480 Programs

Product	Year Introduced	Composition
Cornmeal, enriched[a]	1957 (approx.)	99+% cornmeal, ¼ oz vitamin mineral premix per hundredweight.
Processed cornmeal, enriched[b]	1963	99+% PCM,[c] ¼ oz vitamin-mineral premix per hundredweight.
Ceplapro[b]	1965	58% cornmeal, 25% soy flour, 10% durum flour, 5% NFDM, 2% vitamin-mineral premix.
CSM (corn-soy-milk)	1966	59.2% PCM, 17.5% soy flour, 15% NFDM, 5.5% soy oil, 2.8% vitamin-mineral premix.[d]
Instant CSM	1971	63% instant PCM, 23.7% soy flour, 5% NFDM, 5.5% soy oil, 2.8% vitamin-mineral premix.[d]
Instant sweetened CSM	1971	53% instant PCM, 27.5% soy flour, 7.35% sucrose, 5% NFDM, 5% soy oil, 2% vitamin-mineral premix, 0.15% vanilla flavor.
Soy-fortified cornmeal	1972	85% cornmeal, 15% soy grits.
CSB (corn-soy blend)	1973	67% PCM, 25% soy flour, 5% soy oil, 3% vitamin-mineral premix.

[a] According to Tollefson (1967), between 1957 and 1967 approximately 140 million tons was sold for U.S. aid programs.
[b] Product was tested in more than thirty countries, but never purchased under PL480.
[c] PCM = processed cornmeal, NFDM = nonfat dry milk.
[d] The original formulas for these products called for 64% PCM, 24% soy flour, 5% NFDM, 5% soy oil, and 2% vitamin-mineral premix. Present requirements were described by Bookwalter (1981).

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preceding section and by Conway (1971a, 1971b). Other forms of cooking have been described by Anderson et al (1969, 1970), although the extruder appears to be the most versatile and practical cooking equipment for dry-milled corn products.

Although soy flour and soy grits have been the main protein supplement used in PL480 products (alone or in combination with NFDM), other protein sources have been investigated. Cantor and Roberts (1967) described the use of fish protein concentrate in producing materials equivalent to CSM in protein efficiency ratio. They also discussed the possible use of amino acid fortification. Hayes et al (1978, 1983) examined the replacement of soy flour in both corn- and wheat-based products with both defatted cottonseed and peanut flours. Whey protein concentrate was also tested and eventually approved as a replacement for NFDM and for use in a whey-soy drink mix (Bookwalter, 1981).

RESULTS OF PL480 PROGRAM

The main thrust of the PL480 program has never been to continue indefinitely the donation of food products to less developed countries, but to provide a stop-gap measure until adequate agricultural and processed food products could be produced by local governments. However, this stop-gap program has been going on for over 30 years and will probably continue into the foreseeable future.

Nevertheless, the efforts expended in this and other programs have been quite fruitful. The author is aware of at least 60 different products developed by various companies, governments, and foundations, many of which are being sold directly to people or local governments by private industry (Anonymous, 1970). Products with such names are Areparina, BalAhar, Duryea, Incaparina, Modern Bread, Pronutro, Saridele, Superamine, Golden Elbow Macaroni, and Yoo Hoo are but a few of the cereal-based foods that have helped to relieve part of the hunger problem. Add to these the 15–20 fortified cereal products, plus the many other commodity-based foods sold to and distributed by the U.S. government, and one begins to get a picture of the total energy and resources spent in this area in the last 30 years.

TABLE VI
Quantities (million lb)[a] of Corn-Based Fortified Foods Sold to Government Agencies under PL480

Product	1970[b]	1974[b]	1977[c]	1979[d]	1980[d]	1981[d]	1982[d]
Cornmeal, enriched	...	...	...	0.3	8.1	57.4	54.3
Soy-fortified cornmeal	...	25.5	...	105.6	108.2	133.9	83.1
Corn-soy blend	...	191.6	...	7.3	...	2.4	2.0
Corn-soy-milk (CSM)	383.5	...	...	226.5	247.3	282.9	215.4
Instant CSM	...	40.7	...	65.3	82.4	70.7	45.6
Instant sweetened CSM	...	31.4	...	...	...	...	...
Totals	383.5	289.2	485.0	405.0	446.0	547.0	400.4

[a] Divide figures in this table by 2205 to convert to million metric tons.
[b] Data from R. J. Alexander. Creating new foods from corn and other grains, paper presented to A Workshop on Food Engineering, Texas A&M University, May 19–21, 1975.
[c] Unpublished data; no information available on specific products.
[d] Data from Bookwalter (1983); values converted from metric tons to pounds.

products have been developed for use with petrochemical-based synthetic polymers. Russell[11] discussed the use of flours as extenders in polyvinyl alcohol and polyvinyl chloride films used as agriculture mulches. Cereal flours have also been used as polyol-extenders in rigid polyurethane foams (Bennett et al, 1967), in flexible polyurethane foams (Hostettler, 1978), and in polyurethane resins (Otey et al, 1968), which can be molded and machined into furniture parts and the like. In certain polyurethane foams (Anonymous, 1967; Bennett et al, 1967), the flour appears to function as a fire-retarding agent as well as an extender.

Miscellaneous. A number of other minor uses for dry-milled corn products have been reported, including explosives, carriers for vitamins in animal feeds and for certain pesticides, and abrasive agents in industrial hand soaps (Alexander, 1973); as textile sizes (Rankin et al, 1963); and as a dry carrier in solvent-based dry cleaners.[12]

F. By-Products and Animal Feed

As indicated in Section II of this chapter, the various by-product streams from the corn dry-milling process are most frequently combined to produce a single by-product known as hominy feed. The volume of this product, the largest for the products sold by the dry corn millers, is annually about 2.2 billion pounds (Brekke, 1970a; Alexander, 1973). This material competes with similar corn by-products, such as corn gluten feed and spent brewer's grains (Shroder and Heiman, 1970), as ingredients in animal feed. This area has been the subject of fairly comprehensive reviews (Morrison, 1959; Smith, 1959; Shroder and Heiman, 1970; Ensminger and Olentine, 1978) and is not reported here in any detail.

Hominy feed provides the U.S. feed industry, as well as numerous countries throughout the world, with an inexpensive, high-fiber, high-caloric ingredient. The material is high in carotenoids (the yellow pigments in corn) and in vitamins A and D. The high carotenoid content is particularly desirable in chicken feed for providing eggs with bright yellow yolks.

In recent years, a number of investigators have taken a close look at alternative, potentially more profitable uses for some of the by-product streams, in particular, corn bran and oil-free corn germ. Corn bran has been of particular interest because of its potential as a source of dietary fiber (Wells, 1979). One researcher (DuVall, 1982) incorporated dry-milled corn bran of a certain specific particle size into an extruded, high fiber, corn-based breakfast cereal. At least one dry-milled product (Anonymous, 1977; Tabor Milling Company, 1977) was introduced as a high-fiber ingredient for food applications. Others (Alexander and Krueger, 1978) have taken advantage of corn bran's superior water absorption properties in providing an extender-viscosifier for use in urea-formaldehyde plywood adhesives.

Oil-free, dry-milled corn germ, especially that produced by hexane extraction, is a good source of high-quality protein (Blessin et al, 1972, 1973; Garcia et al,

[11] C. R. Russell. Cereal starches and flour products as substitutes and extenders for petroleum-based polymers and plastics. Presented to: American Corn Milling Federation meeting, Northern Regional Research Laboratory, Peoria, IL, June 1975.

[12] See footnote 3.

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1972), plus a fairly good source of dietary fiber. Such material has recently received considerable attention as an ingredient in protein-fortified cookies (Blessin et al, 1972, 1973; Tsen 1976), bread (Tsen et al, 1974), and other food products, such as corn muffins and meat patties. At least one dry corn milling company reportedly produced pilot plant quantities of a corn germ flour for evaluation during the mid-1970s. The current status of this venture is not known.

By the use of alkaline extraction and dialysis techniques, Nielsen and co-workers (1973, 1977) prepared protein isolates from oil-free corn germ. Products with nutritionally valuable amino acid profiles for potential fortification of food products were described.

Typical analyses of the various by-product streams are shown in Table VII. Composition of hominy feed can vary somewhat depending on whether the corn miller incorporates germ cake into the feed, sells corn germ to another company that processes germ, or finds other ways of upgrading the various streams.

V. FUTURE OF CORN DRY MILLING

Considering the current situation with corn dry milling, it is somewhat difficult to predict what will happen to the industry in the next 10–15 years. On the negative side, the industry has not really grown in recent years. The amount of corn processed by dry millers in 1977–1982 (Anonymous, 1982) is about the same as that reported by Brekke (1970a) for the 1965–1969 period, or about 120–140 million bushels ($3.0–3.5 \times 10^6$ t). Increases in product volumes achieved in certain food and nonfood applications have been offset by decreases in brewing.

On the positive side, some new developments, especially in the food area, could lead to increases in the near future. One area of particular importance has been that of ethnic foods, specifically Mexican and Latin American food products. The number of alkali-processed corn products in both the supermarket and the fast-food and Mexican food restaurants has definitely shown an increase. New corn mills devoted exclusively to the production of masa flour (Rice, 1983) have been built since 1980, and masa flours produced by

TABLE VII
Typical Composition (%, as-is basis) of Dry-Milled Corn By-Product Streams[a]

Component	Standard Meal	Corn Germ[b]	Corn Bran	Hominy Feed
Moisture	14.0	9.6	10.0	13.5
Protein	11.0	15.8	8.0	8.0
Fat	4.5	23.8	4.5	3.4
Crude fiber	2.5	5.7	12.0	4.7
Ash	2.0	6.7	2.5	2.0
Starch	60.0	18.4	35.0	61.0
Other polysaccharides	6.0	20.0	28.0	7.4

[a] Except for hominy feed, the product streams normally do not exist as separate finished products but are combined with broken corn and subsequently dried and hammer milled together to produce hominy feed.
[b] Represents composition before oil expelling or extraction.

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are usually prepared from maize. *Atole* is a smooth, creamy, free-flowing product prepared from wet-milled pastes, dry-milled flours, or degermed flours. On the other hand, a roasted porridge called pinole has characteristics similar to those of *atoles*, but the maize is roasted to promote flavor changes and increase palatability. Flavor development depends upon roasting time, temperature, and the initial moisture content of the grain. Methods to prepare porridges vary among regions. A general scheme (Fig. 5) for preparation of *atole* and pinole in Mexico involves cooking and/or steeping, wet or dry milling, and addition of other ingredients such as milk, sugar, orange leaves, and cinnamon (Vivas, 1985). The same processes are applied to the production of *atoles* from degermed maize flour. The processes summarized in Fig. 5 are similar to those used in some African countries, where *ogi* (thin fermented porridge) and *tô* (thick porridge) are prepared from maize, sorghum, millet, cassava, and rice (Rooney and Murty, 1981). In Africa, the porridges are often fermented and are consumed as the major food three times a day by dipping a portion of the cooled thick porridge into a sauce composed of tomatoes, okra, onions, chiles, and other ingredients. In many areas of Africa, maize is preferred over sorghum or millet because of its flavor and relative ease of processing. For instance, maize grits and meal are available in urban centers because shelf-stable products can be prepared from degermed maize. Sorghum and millet are not as easily degermed; therefore, they do not make shelf-stable products. Thus, maize is consumed in many African countries, which sometimes exacerbates food shortages because maize is not as well adapted to hot, dry conditions as sorghum.

CORN GRITS
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Conditioning
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Steam cooking
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Flaking
|
Drying and cooling
|
Roller milling
|
Sifting
|
Formulating flour
|
INSTANT *AREPA* FLOUR

Fig. 4. Commercial production of instant *arepa* flour.

CHAPTER 15

NUTRITIONAL PROPERTIES AND FEEDING VALUE OF CORN AND ITS BY-PRODUCTS

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I. INTRODUCTION

Of all the grains commonly used in livestock and poultry rations in the United States, corn is by far the most important because it is produced in a quantity substantially over that needed for human food. Corn is palatable, is readily digested by humans and by monogastric and ruminant animals, and is one of the best sources of metabolizable energy (ME) among the grains. The availability of corn and soybean meal, as economical sources of energy and protein, has played a most important role in the rapid growth and development of the livestock and poultry industries. Initially these industries used primarily the by-product materials from the grain milling and beverage industries. As the nutritional needs of farm animals became better known and the demand for balanced rations increased, ground corn became the major ingredient.

Corn contains about 72% starch on a dry basis and is low in fiber. The starch is found in the endosperm as granules in a protein matrix (see Chapter 3). Although corn is low in protein content, the volume utilized makes it a major source of protein for the livestock industry. In 1985, the United States harvested approximately 75.1 million acres (30.4×10^6 ha) of corn having an estimated yield of 118.0 bu per acre (7.87 t/ha) (USDA, 1986). The protein in this much corn is equivalent to 46.7×10^6 tons (42.4×10^6 t) of 44% soybean meal. For comparison, the soybeans harvested during this period (2,098 million bushels [53.3×10^6 t]) would produce about 55.2 million tons (50.1×10^6 t) of 44% soybean oil meal.

Average U.S. consumption of corn by farm animals over the last five crop years (1980/81 to 1985/86) was 107.12×10^6 t ($4,217 \times 10^9$ bu). Distribution by class of animals was: swine, 34%; beef, 22.3%; dairy, 18.2%; poultry, 21.3%; other classes, 5.1%. Swine and poultry consumed an average of 55.3% of the corn, and dairy and beef cattle consumed 40.5%. Although the protein content of corn is low, corn still provides as much as 20–50% of the total protein present

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in many livestock and poultry rations because of the high level of corn used in these diets (USDA, 1985b).

When corn is fed to livestock, it is usually first processed in some manner to improve acceptability or nutritional value. Although whole grain may be fed to swine or cattle, grinding or roll-flaking either dry or wet corn is preferred. Dry grinding of corn permits easier blending with other ingredients but also improves conversion efficiency for swine (Beeson, 1972). Pelleting the mixed feed produces about 10% additional improvement in feed efficiency for swine (Jensen and Becker, 1965). The bulk of poultry feed is pelleted. Aside from the advantages of ease of handling and prevention of segregation of ingredients, pelleted feeds give improved growth rate and feed improvement in poultry. Of all the cereals, corn shows the most improvement from pelleting (Allred et al, 1957).

Feeding corn to feedlot beef cattle provides them a high-energy feed, especially for finishing. Dry roll-flaking the corn may produce an improvement of 2–3% in feed efficiency, but wet processing produces the greatest improvement. High-moisture corn obtained by harvesting at 25–30% moisture content or by rewetting dry corn to that same moisture content (called reconstitution) gives 2–6% improvement in feed efficiency (Hale, 1984). If the high-moisture corn is to be stored more than a few days, it must be treated with a preservative, preferably propionic acid, to prevent mold development (Hall et al, 1974). Steam flaking, which involves a steam cooking step followed by roll-flaking to a bulk density of 22–24 lb/bu (28–31 kg/hl), produces a feed efficiency improvement of 6–10%. However, energy costs must be factored into the benefit calculation (Hale, 1984; Schnake, 1984).

The composition of corn is given in Tables I–III.

TABLE I
Guaranteed and Proximate Analyses of Corn Wet-Milled By-Products[a]

Item	Corn[b]		Corn Gluten Feed		Corn Meal		Germ Meal		Steep Liquor	
	As is	DSB[c]	As is	DSB	As is	DSB	As is	DSB	As is	DSB
Guaranteed, %										
Protein (min.)	···	···	21.0	···	60.0	···	20.0	···	23.0	···
Fat (min.)	···	···	1.0	···	1.0	···	1.0	···	···	···
Fiber (max.)	···	···	10.0	···	3.0	···	12.0	···	···	···
Proximate, %										
Moisture	15.5	···	9.0	···	10.0	···	10.0	···	50.0	···
Protein (N × 6.25)	8.0	9.5	22.6	25.1	62.0	68.9	22.6	25.1	23.0	46.0
Fat	3.6	4.3	2.3	2.7	2.5	2.8	1.9	2.1	0.0	0.0
Fiber										
Crude	2.5	2.9	7.9	8.9	1.2	1.3	9.5	10.6	0.0	0.0
NDF[d]	8.0	9.5	25.4	30.0	4.1	4.8	41.6	48.0	0.0	0.0
Ash	1.2	1.4	7.8	8.6	1.8	2.0	3.8	4.2	7.3	15.6
NFE[e]	69.2	81.9	50.1	55.7	22.5	25.0	52.2	58.0	19.2	38.4
Starch	60.6	71.7	low	low	low	low	low	low	low	low
TDN[f] (ruminants)	75.5		75		86		70		40	

[a] Source: Anonymous (1982a); used with permission.
[b] Anonymous (1982b).
[c] Dry substance basis.
[d] NDF = neutral detergent fiber (Watson, 1986, and Chapter 3).
[e] Nitrogen-free extract.
[f] Total digestible nutrients.

II. NUTRIT

A.

The proteins in corn t
amino acids, methionine
acids lysine and tryptop
lysine and tryptophan bt

Typical Nutrient

Item
ME,[c] kcal/kg (DSB[d])
Chicks
Poults
Hens
Turkeys
Swine
Ruminants
Minerals (DSB)
Potassium, %
Phosphorus, %
Magnesium, %
Chloride, %
Calcium, %
Sulfur, %
Sodium, %
Iron, mg/kg
Zinc, mg/kg
Manganese, mg/kg
Copper, mg/kg
Chromium, mg/kg
Molybdenum, mg/kg
Selenium, mg/kg
Cobalt, mg/kg
Vitamins, mg/kg (DSB)
β-Carotene
Choline
Niacin
Pantothenic acid
Pyridoxine
Riboflavin
Thiamine
Biotin
Inositol
Xanthophyll, mg/kg (DSB)
Linoleic acid, % (DSB)

[a] Source: Anonymous (1982a); use
[b] Anonymous (1982c).
[c] Metabolizable energy.
[d] Dry substance basis.
[e] Estimate.
[f] Data not available.

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By-Products[a]

erm Meal		Steep Liquor	
s is	DSB	As is	DSB
0.0	...	23.0	...
1.0	...	...	...
2.0	...	...	...
0.0	...	50.0	...
22.6	25.1	23.0	46.0
1.9	2.1	0.0	0.0
9.5	10.6	0.0	0.0
41.6	48.0	0.0	0.0
3.8	4.2	7.3	15.6
52.2	58.0	19.2	38.4
low	low	low	low
70		40	

II. NUTRITIONAL VALUE OF CORN PROTEINS

A. Normal and High-Protein Corn

The proteins in corn have a relatively high percentage of the sulfur-bearing amino acids, methionine and cystine, but are very deficient in the essential amino acids lysine and tryptophan (Table III). Soybean protein is a good source of lysine and tryptophan but a relatively poor source of the sulfur-bearing amino

TABLE II
Typical Nutrient Content of Corn and Corn Wet-Milling By-Products[a]

Item	Corn[b]	Corn Gluten Feed	Gluten Meal	Germ Meal	Steep Liquor
ME,[c] kcal/kg (DSB[d])					
Chicks	3,818	2,007	4,131	1,822	3,110
Poults	...	1,813	4,131[e]	1,711[e]	3,110[e]
Hens	3,818	2,007	4,131[e]	1,956[e]	3,110[e]
Turkeys	...	2,321	4,131[e]	2,078[e]	3,110[e]
Swine	3,762	2,635	3,907	3,296	NA[f]
Ruminants	3,420	3,249	3,510	2,850	NA
Minerals (DSB)					
Potassium, %	0.37	1.4	0.50	0.38	4.8
Phosphorus, %	0.29	1.0	0.78	0.56	3.6
Magnesium, %	0.14	0.46	0.17	0.18	1.42
Chloride, %	0.05	0.25	0.11	0.04	0.86
Calcium, %	0.03	0.2	0.02	0.04	0.28
Sulfur, %	0.12	0.18	0.92	0.36	1.18
Sodium, %	0.03	0.13	0.03	0.04	0.22
Iron, mg/kg	30	334	186	367	220
Zinc, mg/kg	14.0	97	47	118	132
Manganese, mg/kg	5.0	24	trace	4.1	58
Copper, mg/kg	4.0	10.9	24	4.9	31.2
Chromium, mg/kg	...	<1.5	<1.5	<1.5	<2.0
Molybdenum, mg/kg	...	0.9	0.67	0.56	2.0
Selenium, mg/kg	0.08	0.24	0.73	0.37	0.7
Cobalt, mg/kg	0.05	0.1	0.0	0.0	0.28
Vitamins, mg/kg (DSB)					
β-Carotene	3.0	0.0	49–73	0.0	0.0
Choline	567	2,659	2,444	1,564	6,996
Niacin	28.0	82	90	46	167
Pantothenic acid	6.6	19	3.2	4.9	30
Pyridoxine	5.3	16	6.8	6.6	18
Riboflavin	1.4	2.7	2.4	4.2	12
Thiamine	3.8	2.2	0.24	6.8	6
Biotin	0.07	0.2	0.24	0.24	0.66
Inositol	NA	5,923	2,102	NA	12,012
Xanthophyll, mg/kg (DSB)	19.0	24[e]	244–550	0.0	0.0
Linoleic acid, % (DSB)	2.05	2.4[e]	3.6	0.6[e]	0.0

[a]Source: Anonymous (1982a); used by permission.
[b]Anonymous (1982c).
[c]Metabolizable energy.
[d]Dry substance basis.
[e]Estimate.
[f]Data not available.

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acids. Hence, a mixture of corn and soy proteins complement each other quite well in poultry and swine diets.

Corn protein content, and its amino acid ratios, may vary widely due to genetic manipulation by plant breeders (Chapters 2 and 9) and to a lesser degree

TABLE III
Typical Amino Acid Content of Corn and Corn Wet-Milling By-Products[a]

Item	Corn[b]	Corn Gluten Feed	Gluten Meal	Germ Meal	Steep Liquor
Protein,[c] % (DSB[d])	9.5	24.5	68.9	25.1	46.0
Amino acids,[e] % (DSB)					
Lysine	0.22	0.65	1.1	1.0	1.6
Methionine	0.15	0.55	2.1	0.7	1.0
Cystine	0.19	0.55	1.2	0.44	1.6
Tryptophan	0.07	0.11	0.33	0.22	0.1
Threonine	0.31	1.0	2.2	1.2	1.8
Isoleucine	0.34	0.7	2.6	0.8	1.4
Leucine	1.05	2.1	11.1	2.0	4.0
Phenylalanine	0.42	0.9	4.2	1.0	1.6
Tyrosine	0.33	0.7	3.2	0.8	1.0
Valine	0.38	1.1	3.0	1.3	2.4
Histidine	0.25	0.8	1.3	0.8	1.4
Arginine	0.42	1.1	2.1	1.4	2.2
Glycine	0.37	1.1	1.8	1.22	2.2
Serine	0.44	1.1	3.4	1.1	2.0
Alanine	0.78	1.7	5.8	1.6	3.6
Aspartic acid	0.68	1.3	4.0	1.6	2.8
Glutamic acid	1.77	3.7	15.3	3.6	7.0
Proline	0.84	1.9	6.1	1.4	4.0

[a]Source: Anonymous (1982a); used by permission.
[b]Anonymous (1982c).
[c]Protein = N × 6.25.
[d]Dry substance basis.
[e]Listed in approximate decreasing order of importance in feed formulation. Lysine through serine are essential amino acids or have sparing effects. Alanine through proline are nonessential.

TABLE IV
Biological Value of Protein in High- and Low-Protein Corn[a]

Corn Source	Protein (%, DSB[b])	Zein[c] (%)	Tryptophan (%)	Lysine (%)	Biological Value (BV)[d] (%)
U.S. hybrid 13					
Continuous planting	7.32	23.2	0.87	2.92	68.6
Corn, oats, clover rotation	10.73	32.9	0.75	2.72	63.1
Illinois high-protein corn					
Nitrogen deficient	13.47	46.4	0.71	2.19	46.9
Nitrogen fertilized	20.04	57.7	0.55	1.76	44.7

[a]Source: Mitchell et al (1952); used by permission.
[b]Dry substance basis.
[c]Protein extracted by 71% ethanol.
[d]
$$BV = \frac{[\text{Food N} - (\text{fecal N} - \text{metabolic N}) - (\text{urinary N} - \text{endogenous N})]100}{\text{Food N} - (\text{fecal N} - \text{metabolic N})}$$

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although it is highly toxic at a level not much higher than the requirement level. Many soils in the U.S. are deficient in this element, but some soils have an excess, causing "alkali disease" (Kubota and Alloway, 1971). Vitamin E and selenium share in an antioxidant biological function (Oldfield, 1985).

VI. ANTINUTRIENTS

Mycotoxins are metabolites produced by fungi that grow on corn kernels produced or stored under adverse conditions (Shotwell, 1977; see also Chapter 5). They are not a natural component of sound corn. When they are present at toxic levels in corn fed to animals, various disease symptoms may develop, some which are very severe. Some of the symptoms of mycotoxicosis in animals are reduced growth, feed refusal, lowered resistance to certain infections, reproductive failure, teratogenesis, and carcinogenesis. The most important mycotoxins causing economic losses in corn are aflatoxins, zearalenone, trichothecenes, and ochratoxins (Hesseltine, 1979).

Of the mycotoxins, aflatoxins are the most serious threat to animal and human nutrition because they possess acute and subclinical toxicity and carcinogenicity. Poultry, especially ducklings and turkey poults, young swine, pregnant sows, calves, and dogs are highly susceptible. The toxin is excreted in the milk. Stunting or "poor doing," liver damage, anorexia, and depression are common symptoms of aflatoxin toxicosis, and the young of most animals are more susceptible than adults to a given dosage. Aflatoxin is highly stable to the level of heat generally encountered in the processing of grain. In a laboratory wet-milling procedure, all of the toxin was found to be concentrated in the steep liquor, fiber, gluten, and germ, in that order (Yahl et al, 1971).

The U.S. Food and Drug Administration established a 20-ppb action level for aflatoxin in human food in about 1978. A periodic exemption allows corn containing 20–100 ppb of aflatoxin to be shipped interstate, provided it is to be fed solely to mature, nonlactating livestock.

Corn contains only low levels of the natural antinutrionts trypsin and chymotrypsin inhibitors.

VII. CORN FEED BY-PRODUCTS FROM FOOD PROCESSES

Three major processes are used to manufacture food products from corn. These are the wet-milling and dry-milling processes and the corn distilling process for beverage alcohol. Fuel alcohol is produced by wet milling and by a dry milling process. Approximately 1,065 million bushels (27×10^6 t) of corn was used in the United States by these three industries during the 1984/85 crop year (USDA, 1986). The wet-milling industry was estimated to have used 74.6% of this corn, including 14.1% for conversion to ethanol. Direct fermentation of corn amounted to 8.45% for ethanol. About 14.1% was used for alkaline-cooked food products and the dry-milling process for food and industrial uses. These uses accounted for about 15.2% of the 1984/85 disappearance of 7,019.8 million bushels (178.2×10^6 t) out of a total supply of 8,400.5 million bushels (213.3×10^6 t). Analysts at the U.S. Department of Agriculture estimated the total U.S. corn

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VIII. CORI

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supply for 1985/86 to be 10,274.5 million bushels (260.9 × 10^6 t). They estimated an increase in 1985/86 for regular wet-milled products of 25 million bushels and an increase of 20 million each for ethanol from wet milling and direct fermentation (USDA, 1986).

In each of these processes, only 65–70% of the corn is converted to primary end products. An exception is alkaline-cooked corn food products (Chapter 13), which utilize whole corn. The remainder of the corn is by-products, most of which are utilized as ingredients in animal feeds and are estimated at 9–10 million tons (8.2–9.1 × 10^6 t). Most of the feed products from the fermentation and dry-milling industries are used by the U.S. feed manufacturing industry. In the case of the major feed by-product from the wet-milling process, corn gluten feed (CGF), approximately 80% of the 5 million tons (4.54 × 10^6 t) produced annually is exported, mainly to Europe (Wookey and Melvin, 1981; Watson, 1986). All by-product feed materials are given official definitions and international code numbers by the American Association of Feed Control Officials (AAFCO, 1986). Feed formulators must use these definitions and code numbers in dealings with the U.S. Food and Drug Administration or other official bodies and on sales contracts.

The discussion that follows deals extensively with the wet-milling industry for several reasons. One is that wet-milling products dominate the market due to their large volume. Another is that the corn wet-milling industry has been pressed to find new markets for a rapidly growing volume of by-products. This industry has experienced an 8–10% annual growth rate from 1979 to 1985, resulting in a 3.5-fold grind increase since 1972 (USDA, 1985a). The industry has conducted considerable research on product properties both in-house and at major universities. This has resulted in a significant body of literature that has not been adequately summarized heretofore. Although domestic utilization was increased, the major relief was found by developing markets overseas for CGF densified by pelleting (Watson, 1986). Most CGF sold domestically is now in the pelleted form except for that marketed in the wet state.

The Distillers Feed Research Council (Anonymous, 1982b) has also sponsored research for many years and has published most of the results in its annual proceedings of the distiller's feed research conferences and in other publications. Very little literature is available on hominy feed, the single feed by-product of the corn dry-milling industry, for reasons discussed later. Furthermore, results from feeding trials of wet-milled products are similar to those of dry-milled products and are somewhat cross-applicable due to the fact that all feeds are comprised of the fibrous and proteinaceous components of the corn kernel.

VIII. CORN WET-MILLING FEED PRODUCTS

The primary products from the wet-milling process are food and industrial starches and sweeteners. By-products include corn oil and the feed products CGF, CGM, corn germ meal, and condensed fermented corn extractives (steep liquor). (See Chapter 12 for a complete description of the process.) The derivation of the by-products is shown graphically in Fig. 1. They constitute about one third of the weight of the original corn. The germ is solvent-extracted to recover oil, and the extracted germ meal is used in feed products. The gluten is

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separated from starch by centrifuges, giving a stream containing 69–72% (dry substance basis) total protein, which is dried to become 60% protein CGM. The solubles removed from the corn during steeping are concentrated by evaporation and are called steep liquor or condensed fermented corn extractives. The steep liquor, corn germ meal, and bran are separate components at this point in the process and may be processed and sold as separate products. Condensed fermented corn extractives are usually sold on a 50% solids basis. The corn germ meal is also sold at times at a premium price over CGF. Its absorptive properties and its good amino acid content and balance render it a valued material for use as a carrier for micro-ingredients in formulated feed, but it is primarily a component in CGF. The corn bran (fiber), corn germ meal, and condensed fermented corn extractives are combined in the proportions obtained from the process to become CGF, which is marketed in a wet or dried form. In the dry form, it has a protein content of 21.0%. These components may also be combined in special proportions to produce two other products: condensed fermented corn extractives with germ meal and bran, dehydrated (which is 25–30% protein) and 10% protein corn gluten feed (the entire bran stream with nothing added). The bran can be sold in the wet or dry state.

Wet CGF, containing a minimum 40% dry substance, is being marketed by some corn wet-milling processors. The primary reason is the high cost of energy

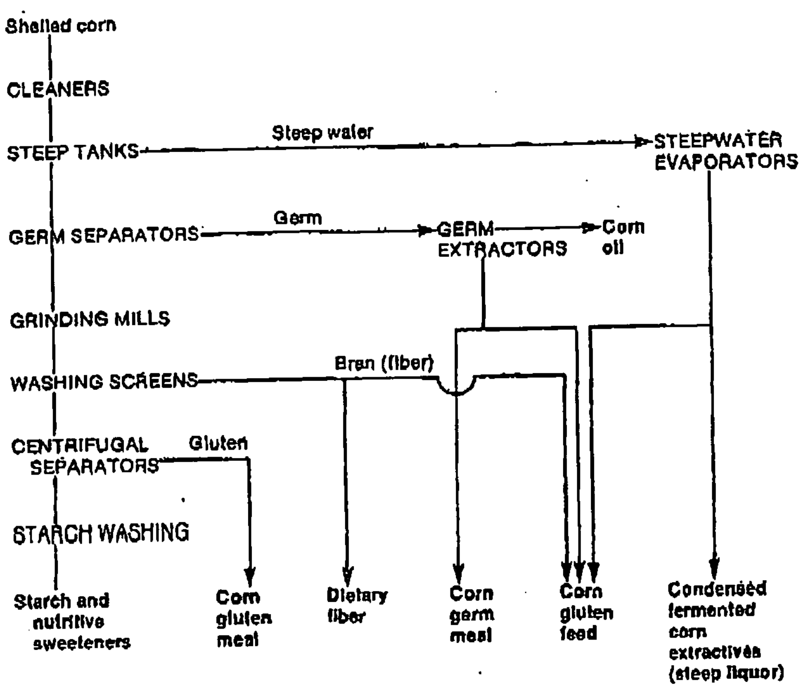

Fig. 1. The corn wet-milling process.

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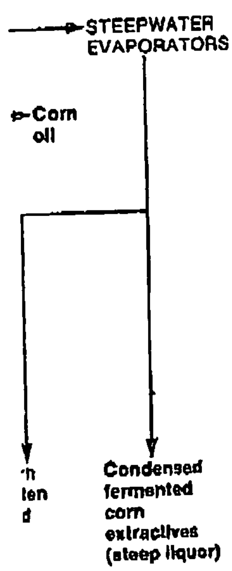

and equipment to dry the product. The nutritive content of the wet feed is very similar to that of the dry feed expressed on a dry basis. The maximum storage time for open wet CGF outside under some conditions approximates seven days or less. Molds will grow on wet CGF stored under certain conditions, but storage conditions should be such as to prevent mold development, which usually is deleterious to feed value.

Domestic corn utilization by the wet-milling industry increased sharply during the period 1981/82 to 1985/86 from 581 million bushels (14×10^6 t) to approximately 840 million bushels (21.3×10^6 t) annually (USDA, 1986). Most of the increase supplied the rapidly developing market for high-fructose corn sweeteners and fuel alcohol. By 1985/86, the growth in corn usage had also made available additional coproducts approximating 2.1 million tons (1.9×10^6 t) of CGF, 450,000 tons (408×10^3 t) of 60% CGM, and 480 million pounds (108×10^3 t) of corn oil per year. A new crystallizing process for pure fructose has recently been developed; the USDA (1986) has predicted that fructose will eventually compete directly with table sugar, which will increase the supplies of the coproducts still further. The nutrient contents of corn wet-milled feed products are given in Tables I–III.

A. CORN GLUTEN FEED

CGF is a feed ingredient with a medium protein level and is palatable to all classes of livestock and poultry. In spite of its name, CGF does not contain any gluten. It is comprised of the fiber fraction (bran), steep liquor, and, where available, germ meal. It commonly contains a minimum of 21% crude protein and approximately 15% starch (Reiners and Howland, 1976). The proximate analysis (Table I) of CGF reflects the effects of starch, gluten, and oil removal on the concentration of the remaining protein, ash, crude fiber, vitamins, and minerals in the corn. The amino acid profile (Table III) is similar to that of whole corn unless the germ meal is not included, as is the case in certain of the wet-milling plants. The energy content of CGF (Table II) varies with the species and application. The ME content is about 92, 71, and 52% that of corn for cattle, swine, and poultry, respectively. The high energy value of CGF for cattle reflects the ability of ruminants to readily digest the cellulose and hemicelluloses present. Unless significant quantities of gluten protein are included in the CGF, the xanthophyll content is only slightly higher than that of corn.

The high solubles content of CGF may cause shipping and storage problems. The product is prone to cake and heat in rail cars, barges, and silos if not dried and cooled properly before being loaded. It is more apt to cake and heat, even to the point of combustion, during the summer months when the temperatures and relative humidity are higher. During this period, its tendency to cake and heat can be reduced if the product is dried to less than 9–10% moisture and cooled to less than 40–43° C before being loaded.

BEEF CATTLE

Corn CGF has been fed to cattle for many years, dating back to as early as 1888 (Turk, 1951). It is a palatable feed ingredient for ruminants. Both dry and wet CGF have rumen protein escape values similar to those of soybean meal (Firkins et al, 1984). Rumen protein escape values are based on relative

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performance resulting from dietary protein that escapes digestion in the rumen, passes to the abomasum, and is then available for digestion in the lower gut.

Production of rumen total volatile fatty acids was found to be similar for soybean meal and CGF in fistulated steers fed a diet of cottonseed hulls and equivalent amounts of digestible nitrogen (Davis and Stallcup, 1967). The CGF is low in calcium (0.2%) and thiamine (2.2 mg/kg) but high in phosphorus (0.9%). The phytate phosphorus is readily available to the ruminant (Nelson, 1976). Calcium supplementation is required to help maintain a satisfactory Ca-P ratio of at least 1:1 for beef and 1.5:1 for diary cows with high levels of CGF dry matter intake.

When high levels of CGF dry matter, above 30–40%, are used in the total diet, it is desirable to supplement with thiamine to help prevent polioencephalomalacia (polio), which is caused by a thiamine deficiency (Siegmund, 1973). The use of SO_2 in the steeping process reduces the thiamine level in the corn during steeping and therefore in the feed produced. It may also interfere with adequate thiamine synthesis in the rumen.

CGF can be used in large quantities in beef cattle growing-fattening rations because of its high-energy dietary fiber content, high rate of digestibility, and semibulkiness.

Several feeding trials have been conducted on the use of CGF in growing and fattening beef cattle rations. The University of Illinois reported on feeding trials, evaluating both wet and dry CGF in balanced rations for growing and fattening

TABLE VII
Use of Corn Gluten Feed in Growing and Fattening Steer Diets[a,b]

	Control	Dry Corn Gluten Feed 35%	Dry Corn Gluten Feed 50%	Wet Corn Gluten Feed 35%	Wet Corn Gluten Feed 50%	Wet Corn Gluten Feed 70%	Wet Corn Gluten Feed 90%	Urea 0.7%
Trial 1[c]								
Daily gain, kg	1.24	1.52	...	1.46	...	...	...	...
Daily feed, kg	9.61	10.42	...	9.52	...	...	...	...
Feed/gain	7.73	6.86	...	6.52	...	...	...	...
Trial 2[d]								
Daily gain, kg	1.33	...	1.35	...	1.38	...	...	1.27
Daily feed, kg	8.13	...	9.46	...	8.80	...	...	7.76
Feed/gain	6.13	...	7.01	...	6.37	...	...	6.13
Trial 3[e]								
With 10% corn silage								
Daily gain, kg	1.24	...	...	...	1.34	...	1.26	...
Daily feed, kg	6.40	...	...	...	8.80	...	8.85	...
Feed/gain	11.80	...	...	...	6.57	...	7.04	...
Condemned liver, %	11.8	...	...	...	14.7	11.9	...	...
Without corn silage								
Daily gain	...	...	...	...	1.32	1.32	1.22	...
Daily feed	...	...	...	...	8.53	8.57	8.07	...
Feed/gain	...	...	...	...	6.48	6.47	6.64	...
Condemned liver, %	...	...	...	...	35.30	23.5	32.40	...

[a] Adapted from Firkins et al (1985).
[b] Percentages of additions to feed are on dry substance basis.
[c] Trial 1: 98-day, growing, 11.5% crude protein, 275-kg steers.
[d] Trial 2: 113-day, finishing, 12.0% crude protein, 328-kg steers.
[e] Trial 3: 150-day, finishing, 12.0% crude protein, 328-kg steers.

steers (Firkens et al, 198
summarized in Table VII.
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Item
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Daily gain, kg
Intake, kg/day
Feed/gain
Trial 2 (corn silage)[e]
Daily gain, kg
Intake, kg/day
Feed/gain

[a] Courtesy R. A. Barclay.
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Diets[a,b]

luten Feed		Urea
70%	90%	0.7%
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...	...	...
...	...	...
...	...	1.27
...	...	7.76
...	...	6.13
...	1.26	...
...	8.85	...
...	7.04	...
11.8	...	...
1.32	1.22	...
8.57	8.07	...
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steers (Firkens et al, 1985). Results from some of their reported trials are summarized in Table VII. These data suggest that either dry or wet CGF may be included at 50% or more of the diet dry matter without depressing feed lot performance. The relative cost of nutrients from CGF and the feeding situation should determine the level of usage.

Wet CGF reduces the versatility of use, and requires special handling, equipment, storage facilities, and management. The nutrients are diluted and may decrease to as little as 40%, wet basis, of their level in dry feed (91%). The transportation cost on a dry basis is increased accordingly.

Although corn bran is not now a product readily available to the feed industry, the feeding value of the product helps to determine the value of CGF. Corn bran (fiber) composes approximately 50–55% of the dry matter in CGF.

Two feed lot trials were conducted by the University of Illinois to determine the relative feeding value of corn, corn bran, and soyhulls as energy source in diets based on corn silage or fescue silage (Barclay et al, 1985). The results are summarized in Table VIII. No interactions were observed between ingredient level and energy source. Gain and dry matter intake were not different between the control diet containing corn and the other energy sources. The feed-gain ratio was poorer for soy hulls than for corn or corn bran. Comparison of the 25 and 50% levels of corn bran and soy hulls in the fescue silage-based diet showed that gain, dry matter intake, and feed-gain ratio were improved by increasing the levels of the energy sources. However, in corn silage-based diets, gain and feed-gain ratio were not affected by ingredient levels. Apparently, corn bran and soy hulls may be substituted for corn as energy sources in high-fiber diets with little or no depression in performance.

A recent study has been conducted to determine whether corn bran reduces the negative associative effects of fiber digestion often seen with corn supplementation (Klopfenstein et al, 1985a). Calves ate more feed, gained faster, and were more efficient when 25 or 50% of a corn cob and alfalfa haylage ration was replaced by either a corn grain or corn bran supplement. The calves ate more dry matter when fed corn but were more efficient when fed corn bran. These data

TABLE VIII
Feedlot Performance of Steers Fed Corn Bran and Soyhulls[a]

	Effect of Energy Source[b]			Effect of Energy Level[c]	
Item	Corn	Corn Bran	Soy Hulls	25%	50%
Trial 1 (fescue silage)[d]					
Daily gain, kg	1.15	1.15	1.11	0.96 a	1.32 b
Intake, kg/day	6.36	6.14	6.55	5.91 a	6.82 b
Feed/gain	5.56 a	5.43 a	6.00 b	6.17 a	5.16 b
Trial 2 (corn silage)[e]					
Daily gain, kg	1.39	1.35	1.30	1.33	1.37
Intake, kg/day	10.27 a	9.95 b	10.43 c	10.10 a	10.60 b
Feed/gain	7.39 a	7.37 a	8.25 b	7.59	7.6

[a]Courtesy R. A. Barclay.
[b]Values in a row that are followed by different letters differ at a level of $P<0.01$.
[c]Values in a row that are followed by different letters differ at a level of $P<0.05$.
[d]Ninety-six crossbred steers (203 kg).
[e]Seventy-two crossbred steers (360 kg).

suggest that a 25% corn bran addition does not reduce fiber digestion and that the 50% level of bran does to some extent but not as much as corn does.

DAIRY CATTLE

CGF has been fed to dairy cows probably longer than to any other species. Before the 1900s, the milk-producing properties of CGF were recognized. Turk (1951) has summarized early feeding trials on the ability of CGF to replace such protein supplements as linseed meal, cottonseed meal, peanut meal, and soybean meal in dairy rations composed of corn, oats, and wheat bran along with the roughages soybean and/or alfalfa hay and corn silage. A 1936 Connecticut experiment showed that a grain mixture containing 70% CGF had no effect on the titratable acidity of milk. According to Turk (1951), the Cornell University Agricultural Experiment Station in 1943 studied the relative biological value of CGF and other protein sources in a simple grain mixture. In a total of 86 lactations, averages of the results of five experiments showed no differences in milk production, palatability of the rations, or maintenance of body weight. In other Cornell experiments (1944), 25 and 50% levels of CGF in the concentrate mixture were compared with the Cornell test cow mixture. CGF fed at a level of as much as 50% of the concentrate did not decrease palatability; the mixtures were as efficient in producing milk as a more common mixture of farm-grown grains and by-product feeds and gave satisfactory results.

CGF was found to be a substitute for copra meal and ground yellow corn in rations for lactating dairy and Murrah cows; it can be a substitute also for copra meal in rations for growing dairy heifers but cannot substitute for ground yellow corn in rations for growing Murrah heifers (Clamohoy et al, 1968).

The feeding value of wet CGF for dairy heifers was studied by Jaster et al (1984). The wet CGF was ensiled in a plastic silo bag and showed good preservation and keeping qualities, as measured by changes in pH, temperature, and organic acid concentration. Heifers were fed the wet CGF to determine ad libitum intake and were observed to consume 2.4% of their body weight in dry matter. The apparent digestibility of wet CGF dry matter was found to be 76.6%, compared to those of alfalfa haylage (60.7%), oatlage (53.3%), and sorghum-soybean silage (54.9%). Heifers consuming wet CGF also showed higher digestibility values for neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, hemicelluloses, and crude protein than when fed the other feeds. In an 83-day performance feeding trial involving 64 dairy heifers (275 kg), weight gain and body growth measurements were distinctly superior for dairy heifers fed wet CGF than for those fed alfalfa haylage (Table IX) and other forages. However, because of excessive body weight gain and mild diarrhea, it was recommended that wet CGF not be fed free choice as the sole feed to replacement dairy heifers. Other feeding studies with lactating cows (Staples et al, 1984) showed that when wet CGF was ensiled and fed with corn silage, a 25–30% (dry matter basis) replacement of corn grain with wet CGF gave best results.

The effect of the roughage-concentrate ratio on milk production and changes in body weight is discussed by McCullough (1973). Mertens (1985) suggested that NDF and ADF contents and particle size of ingredients are related to energy content, filling effect, and chewing activity. The levels of wet CGF, on a dry matter basis, used in the above experimental rations significantly increased

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Improvement in milk butter fat content has been observed by the author when either CGF or corn bran (wet-milled) was used at relatively high levels as a major source of energy in a concentrate fed to lactating cows. Similar results have been reported by Hutjens et al (1985). The ability of feeds containing CGF or bran to maintain or improve butter fat percentage probably is due to the low amount of starch and the higher level of digestible NDF in the diet, compared to the level in rations containing corn or hominy feed. These high-energy, high-dietary-fiber ingredients can be used very advantageously to formulate high nutrient-density dairy concentrates that maintain or increase butter fat production without decreasing milk production.

SWINE

The ME content of CGF for swine has been reported as 2,770 kcal (Yen et al, 1974) and 2,730 kcal/kg of dry matter (Young et al, 1977). These data compare favorably with the data in Table II. The estimated ME values were not significantly affected by pelleting. The amino acid pattern for CGF is similar to that of corn—a good source of the sulfur-bearing amino acids but deficient in the essential amino acids lysine and tryptophan (Table III). CGF is a much better source of vitamins than is whole corn (Table II). As in corn, the niacin present should be considered unavailable (Laguna and Carpenter, 1951).

The use of CGF in growing-fattening swine rations has been studied (Yen et al, 1971; Hollis et al, 1985). CGF may be used in 12%-protein corn-soy finishing rations, replacing corn as an energy source for up to 30% of the ration dry matter without significantly affecting performance (Table X). The protein content was allowed to increase as the level of CGF increased (Yen, 1971). A nonsignificant decrease in daily gain and gain-feed ratio was observed when CGF replaced up to 30% of the corn in a 16%-protein diet fed in meal form to growing pigs. Pelleting the diets resulted in similar gains and gain-feed ratios at all levels. However, when CGF replaced corn and soybean meal in a 12%-protein isonitrogenous diet, the daily gain, daily feed, and gain-feed ratio were significantly depressed at the 20 and 30% levels of dry CGF. It was later demonstrated (Yen, 1971) that the first limiting amino acid was tryptophan and

TABLE IX
Growth and Dry Matter Intake of Dairy Heifers Fed Alfalfa Haylage or Wet Corn Gluten Feed for 83 Days[a]

Item	Alfalfa Haylage	Wet Corn Gluten Feed
Dry matter intake, kg/day	8.5	8.4
Average daily gain, kg/day	0.45	1.1
Increased heart girth, cm	8.3	19.1
Increased height at withers, cm	4.2	6.6
Increased body length, cm	6.6	9.1

[a]Source: Jaster et al (1984); used by permission.

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the second was lysine at the 30% level of CGF in the diet. The data suggest that when CGF is used to replace corn and soybean meal on an isonitrogenous basis, a maximum 10% level of CGF should be used in finishing rations without tryptophan and lysine supplementation.

The results of these trials indicate that the previously observed inefficient use of CGF by swine is not due to bulkiness and/or unpalatability but primarily to amino acid deficiencies, especially to low tryptophan and lysine availability.

Wet CGF is best fed to gestating sows because of their large intestinal capacity and relatively low daily nutrient requirements (Hollis et al, 1985). However, because of its low dry matter and nutrient levels, the sow cannot consume enough nutrients from wet CGF to meet her requirements, especially those for energy, calcium, available phosphorus, trace minerals, salt, vitamins, lysine, and tryptophan. Daily intake should be monitored, and diet supplementation with additional sources of these nutrients is required even at the maximum intake of wet CGF by the sow.

Feeding trials were also conducted on the feeding value of dried condensed fermented corn solubles with germ meal and bran (dried steep liquor concentrate [DSLC]) in swine rations (Harmon et al, 1975a, 1975b). DSLC is a blend of steep liquor solids, corn germ meal, and some corn bran. This product contains ME of 3,788 kcal/kg, dry basis, which is greater than that of corn and soybean meal (Cornelius et al, 1973). Lysine and tryptophan in DSLC were found to be at too low a level for swine, as in CGF. When DSLC was the only amino acid supplement for corn in finishing pig diets, much lower gains and efficiency resulted. A corn-DSLC diet designed to meet the lysine and tryptophan requirements could not be improved by addition of lysine or tryptophan alone but was significantly improved when both amino acids were added (Harmon et al, 1975a, 1975b).

When DSLC was used to provide up to 30% of the total lysine in the diet, performance of young pigs was equal to that of pigs receiving a corn-soybean diet. For finishing pigs, DSLC could replace up to 36% of the total dietary lysine.

POULTRY

The use of CGF is limited in poultry feeds because of its low ME, lysine, and tryptophan content, but it is a good source of methionine and cystine. The "fiber

TABLE X
Performance of Finishing Swine When Dry Corn Gluten Feed Replaces Corn in Ration (61-day trial)[a]

Item	Percent of Dry Corn Gluten Feed[b] 0[c]	10	20	30
Protein (estimated), %[d]	...	13.35	14.7	16.05
Daily gain, kg	0.58	0.58	0.61	0.57
Average daily feed, kg	2.14	2.17	2.31	2.19
Gain/feed	0.27	0.27	0.27	0.25

[a]Source: Yen et al (1971); used by permission.
[b]Each value is an average for 10 pigs individually fed. Initial weight was 47 kg.
[c]The corn-soy control diet contained 12% total protein.
[d]Total protein content estimated by author (N X 6.25).

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fraction" is reported to contain ME at a rate of 1,266 kcal/kg and CGF to contain ME at 1,967 kcal/kg in the dry matter for chicks (Bayley et al, 1971). Corn steep liquor contains ME at 3,110 kcal/kg on a dry matter basis for chicks (Anonymous, 1982a). The ME content of CGF appears to be somewhat variable, and the data suggest that the ME value may vary with the type of bird and the amount of soluble solids. CGF normally contains approximately 25–35% corn soluble solids. Pelleting does not seem to affect the ME content of CGF for chickens or turkeys. CGF has a significant potential for use in commercial layer and breeder rations and grower rations, where energy content is not as critical.

In a Canadian experiment, CGF was used to replace meat meal in rations for growing chicks and laying and breeding birds containing no soybean meal (Slinger et al, 1944). In rations for growing chicks, CGF was satisfactory up to 18% of the diet, with an optimum at around 10%. With layers and breeders, CGF could be used in a mash to replace part of the meat meal on a protein equivalent basis up to 16%. The results reported are not surprising, since meat meal is also marginal in tryptophan content. Other experiments with laying hens have shown that CGF can be included at levels of 10–15% of the diet without decreasing egg production or feed efficiency (Heiman, 1961).

In the author's experience, when CGF is used in balanced poultry diets at levels of up to 10–15% of the ration (assuming that the deficiency of energy, lysine, tryptophan, and calcium and the poor availability of phytin phosphorus and niacin are recognized and corrected for), excellent results can be obtained for chick starters, growers, and layer-breeders (Wright, 1957). However, its use in diets for broiler chickens is rare. The intermediate ME level of CGF for poultry generally gives it poor economic value as an ingredient in a high-nutrient-density ration such as that for the broiler chicken or turkey.

B. CORN GLUTEN MEAL

CGM is the dehydrated protein stream resulting from starch separation (Fig. 1). It has a high nutrient density and usually is sold containing a minimum of 60% total protein (Tables I–III). It is highly digestible, contains ME of 4,131 kcal/kg of dry matter for the chick (slightly higher than corn ME), and is a rich source of available carotenes (49–73 mg/kg) and xanthophylls (244–550 mg/kg, dry matter basis). Its crude protein is highly digestible, a good source of methionine and cystine, but very low in lysine and tryptophan. The amino acid pattern of soybean meal complements that of CGM very well, soybean protein being deficient in methionine and cystine but rich in lysine and tryptophan.

CATTLE

The protein in CGM is insoluble in water and has high rumen bypass properties (Burroughs and Trenkle, 1978; Loerch et al, 1983; Stern et al, 1983). It is superior to most other plant protein sources as measured by using a duodenal collection technique, which gives a relative bypass value of 2 compared to 1 for soybean meal (Klopfenstein et al, 1985b). Tests indicate that approximately 57–60% of the protein will bypass the rumen, compared to about 25% of the protein in soybean meal. Methionine and lysine have been shown to be limiting in ruminant rations under various conditions because the protein synthesized by

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rumen-active microorganisms is deficient in these two amino acids for cattle. This can be corrected by using CGM as a source of bypass protein with another bypass protein that is high in lysine, such as soybean meal treated with additional heat or an aldehyde source, alfalfa meal, blood meal, meat meal, etc. The economics of using bypass protein sources plus nonprotein nitrogen sources, such as urea, is often quite favorable in comparison to using all native protein sources.

Rumen-degradable protein is needed because the carbon chains from carbohydrates and the nitrogen from ammonia sources serve mostly as the foundation for amino acid synthesis by rumen-active microorganisms. However, certain amino acids or their branched-chain volatile fatty acid precursors may not be produced in sufficient quantity to provide maximum protein synthesis when bypass protein is fed (Dehority et al, 1958). Corn steep liquor solids are an excellent high-energy source of the soluble branched-chain amino acids and other amino acids that are readily available to the rumen organisms for protein synthesis (Wright, 1981).

POULTRY

The high nutrient density, ME, and content of sulfur-bearing amino acids and xanthophyll of CGM makes this product a highly desirable poultry feed ingredient. These factors often make CGM more valuable than soybean meal on a protein-cost basis. The high nutrient density of CGM is taken advantage of in many well-balanced broiler feeds with high energy content, and it can be used at a 10% level or more.

Many studies have been conducted on the bioavailability of xanthophylls in CGM for pigmentation of poultry skin and egg yolks (Marusich and Wilgus, 1968; Halloran, 1970). CGM is often used in layer diets as a source of nutrients and for its available xanthophyll content for egg yolk coloration.

The source of corn, and the length of time it has been stored at the time of milling, effect the amount of xanthophyll in CGM (Tables V and VI). The peak level is reached during the period from November to January. Later in the year, when a substantial amount of corn comes out of storage, a marked reduction in the average carotene and xanthophyll contents of CGM made from this corn can be expected. Because xanthophyll is unstable, the xanthophyll content of CGM and other sources being used must be monitored on a shipment basis to help ensure a uniform degree of pigmentation in the skin or eggs.

The high digestibility of CGM makes this ingredient desirable for use in pet foods, especially where low-residue diets are desired or required.

C. Condensed Fermented Corn Extractives (Steep Liquor)

Corn steep liquor is known officially (AAFCO, 1986) as "condensed fermented corn extractives." It is the concentrated solubles obtained from the corn steeping process (Fig. 1). Its solids are rich in organic nitrogen (44–46% protein on a dry matter basis). About half the nitrogen is present as free amino acids; the balance exists as small peptides with very little intact protein (Christianson et al, 1965). It contains relatively high levels of several important vitamins, trace elements, and lactic acid. The lactic acid (10–30%, dry basis) is

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B. Hominy Feed

A typical yield of hominy feed is 35% of corn input, including germ expellor cake (Brekke, 1970). Composition of a typical hominy feed is given in Tables XV and XVI. Since oil yield by expelling is only 1% and by extraction only about 1.25%, much oil remains with hominy feed in any processing configuration. A low-fat product called solvent-extracted hominy feed is also produced.

Hominy feed normally contains about 10.4% protein, 6.9% fat, 6.0% fiber, 20% total (dietary) fiber, and 2,896 kcal of ME per kilogram for poultry on an "as fed" basis (Tables XV and XVI). Many of the uses of hominy feed are similar to those of CGF. The product is generally lower in protein, higher in fat, and much higher in starch than CGF. All the water-soluble substances are present because no water extraction is involved in the process. The removal of most of the fat by expelling or solvent extraction slightly increases the protein, starch, and fiber contents but decreases the fat and ME contents of hominy feed.

Nutritionally, hominy feed resembles whole corn in some respects and can replace some corn in rations. It has a lower bulk density and less starch but more protein, fat, and fiber than whole corn. The ME content for ruminants is 3,740 compared to 3,420 kcal/kg for corn on a dry basis. As with CGF and the distiller's feeds, the starch and the cellulose and hemicellulose in the bran are highly digestible by ruminants.

Poultry utilize the product less efficiently than corn, primarily because of its lower starch and higher celluose and hemicellulose contents. These are partially offset by a higher oil content. Poultry derive approximately 3,208 kcal of ME per kilogram on a dry matter basis from hominy feed compared to 3,818 kcal/kg from corn.

Hominy feed is used widely in dairy feeds because of its high level of fat and high available energy for ruminants. This ingredient is a good substitute for corn in rations for beef cattle and swine. In fattening rations for swine, if a product with a high fat content is used, a possible concern may be its tendency to produce soft pork when used at high levels, because of a higher level of polyunsaturated fat intake (Morrison, 1956). In properly balanced rations, hominy feed can be used satisfactorily to replace a portion of the corn or milo in various poultry rations.

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Application No. 09/637,843
Docket No. 211174
Client: Renessen LLC
Inventor: Ulrich et al.
Title: "PRODUCTS COMPRISING CORN OIL AND CORN MEAL OBTAINED FROM HIGH OIL CORN"
Attorney: JBB/jb
Mailing Date: 08/30/2005

List of Items Submitted:

1. Transmittal. (2 pp. in duplicate - 4 pp. total).
2. Appeal Brief. (14 pp.).
3. Evidence Appendix Reference 1. (11 pp).
4. Evidence Appendix Reference 2. (41 pp).

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